50 years of research and education on thermal insulation of buildings

an era started by the Thermal Insulation Laboratory, 1959

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Technical University of Denmark
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Contents

1 Introduction

The Thermal Insulation Laboratory was inaugurated at the Technical University of Denmark the 29th of May, 1959. The initiative was carried remarkably by Professor Vagn Korsgaard, who was professor at the institute until his retirement in 1991, and has been an active emeritus professor since then.

Even though the very same institute does not exist today, we wish to celebrate the 50 year anniversary here in the summer of 2009 with a technical seminar where we present the education and research which is conducted today at the Technical University of Denmark within some of the same themes: Building energy technology, building services, solar energy, and building physics.

The theme is possibly at least as important today as it has been throughout all the years since 1959. Buildings today are significantly more energy efficient than they were in the first decades of the existence of the Thermal Insulation Laboratory, and research that has been carried out by the institute over the years is a significant part of the reason why buildings are much more energy efficient today.

However, fossil energy sources need to be replaced very soon, as their supply is and will become even more limited in the years to come. The consumption of fossil fuels also needs to be reduced for environmental reasons. And while we still don't have the technology to fully replace fossil fuels, energy efficiency of buildings becomes an even more pertinent issue.

Thus, there is no doubt about the relevance of the subject. We would like to use the occasion of the historical perspective of the anniversary to give a picture of how we teach and research into the subject.

Contributions to this document have been given by all approximately 30 colleagues who are today engaged in the Section for Building Physics and Services at the Department of Civil Engineering.

As editors:

Simon Furbo	Svend Svendsen	Carsten Rode
Associate Professor	Professor	Associate professor, section head

2 Historical background - from the Thermal Insulation Laboratory to the Section for Building Physics and Services

Logo of the Thermal Insulation Laboratory.

The first 25 years (from ”Aktuel energiforskning, Laboratoriet for Varmeisolering, 1959-1984”, Laboratoriet for Varmeisolering, meddelelse 150, 1984):

Thermal Insulation Laboratory in Retrospect
"Laboratoriet for Varmeisolering" (Thermal Insulation Laboratory) at the Technical University of Denmark was established in 1959 on the initiative of Vagn Korsgaard with support from the Danish Building Industry and a number of foundations. The justification was that all fuel was imported and about half of it (mainly oil) was used for heating of buildings and consequently being a heavy burden to our exchange balance. A strong dependency on oil import also had other disadvantages which the first oil crisis (the Suez crisis in 1956) and later oil crises have clearly shown.

An essential reduction of the fuel consumption can be obtained by an effective insulation of new as well as existing houses. This fact is now recognized also politically.

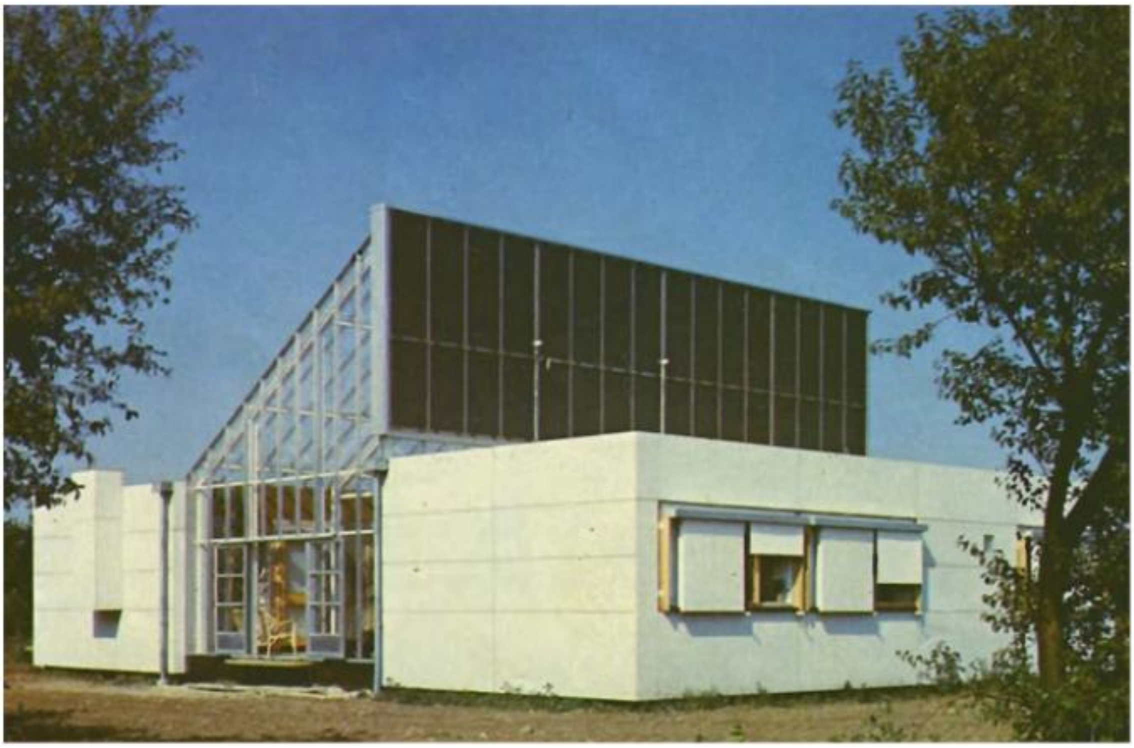
During the sixties the Thermal Insulation Laboratory dealt mostly with thermal indoor climate problems, actualized by "the glass architecture", due to the apparently permanently low oil prices.

During these years the Laboratory developed measuring instruments for determination of the thermal indoor climate based on extensive climate chamber tests carried out by P.O. Fanger and his associates at the Laboratory of Heating and Air Conditioning.

In 1973, V. Korsgaard proposed in the University's newsletter "Sletten" that relevant institutes should cooperate on a project for a low-energy house. One result of the energy crisis in the autumn of 1973 was that the necessary funds for realization of such a project was made available by the Danish Council for Scientific and Industrial Research. The result was the "Zero-Energy House" which was officially opened in April 1975 in the presence of the Danish Queen Margrethe and the Swedish King Carl Gustav.

The research and development activities have since the energy crisis been developed considerably. Especially, new ideas have been taken up being of importance for a reduction of the energy consumption for heating purposes. These are: development of low-energy houses, active as well as passive gain of solar energy and the possibilities of seasonal heat storage.

The increased activity has been made possible by new funds from the Technical University, by funds from the Danish Council for Scientific and Industrial Research, by EEC funds and especially by the considerable grants made available by the Ministry of Energy for increased energy research and development.



The zero energy house.

The Thermal Insulation Laboratory existed until 1996. The institute was merged that year with the Institute of Building Design and the energy group of Fysisk Laboratorium III to form the Department of Buildings and Energy (Institut for Bygninger og Energi, IBE).

Logo of Department of Buildings and Energy

In the year 2000, Department of Buildings and Energy was merged with the Department of Constructions and Materials to form the Department of Civil Engineering (Institut for Byggeri og Anlæg, BYG•DTU). Moist of the activity on building energy was conducted in the group *Bygningsenergi og Installationer*, while the buildings physics part belonged in the group *Building Physics and Materials.*

The institute was reorganized in April 2003, and the Section for Building Physics and Services was established. This section comprised groups for building energy, building services, solar energy, and building physics.

By the beginning of the year 2008 the short name of the institute was changed to *DTU Byg* and some other sections of the institute were changed. The section for Indoor Environment came to DTU Byg from the Department of Mechanical Engineering. However, while the change should encourage closer collaboration between these two sections, the change did not directly involve some organisational change of the Section for Building Physics.

3 Presentation of the Section for Building Physics and Services

3.1 Contact information:

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The section is organized in four research groups:

Building energy
Building services
Solar energy
Building Physics

The activities of the groups are described in the sections on teaching and research. The groups for Building energy and Building services are quite interwoven and will be presented together in the subsequent sections.

3.2 Staff

The Section for Building Physics and Services comprises the following staff (August 2009):

	Building energy	Building services	Solar energy	Building physics
Professor (faculty)				
Svend Svendsen	*	*		
Associate professors (faculty)				
Jørgen Erik Christensen	x	x		
Jianhua Fan		x	x	
Simon Furbo			*	
Hans Janssen				x
Toke Rammer Nielsen	x	x		
Carsten Rode				*
Senior researchers				
Elsa Andersen			x	
Hongwei Li	x	x		
Bengt Perers			x	
Researcher				
Ziqian Chen			x	
Research assistants				
Diana Lauritzen	x			
Henrik M. Tommerup	x	x		
Kristin Osk Tordardottir		x		
Lies Vanhoutteghem	x			
Post Doc				
Gregor Scheffler				x
Ph.d. students				
David Appelfeld	x			
Janne Dragsted			x	
Christian Ancher Hviid		x		
Anne Iversen		x		
Michael Jørgensen	x			
Martin Morelli	x			

	Building energy	Building services	Solar energy	Building physics
Dorthe Kragsig Mortensen		x		
Martin Vraa Nielsen	x			
Steffen Petersen	x			
Alessandro Dalla Rosa	x	x		
Paul Steskens				x
Jacob Strømann-Andersen	x			
Petra Vladykova				x
Eshagh Yazdanshenas			x	

***** Research leader

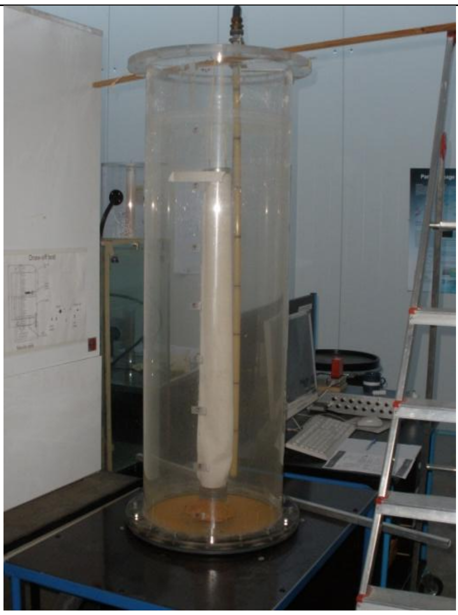
3.3 Facilities

The experimental facilities of the section comprise:

- Hot and cold box chambers with guarded hot box
- Climatic chamber for testing of thermo active building services
- Artificial sun
- Gonio-spectrometer
- Infrared thermography
- Blower door test equipment
- Test stand for cold piping insulation
- Outdoor test field for testing of building envelope components
- Outdoor test cells for hygrothermal testing of rooms and components
- Outdoor test stand and test room for testing of daylight control systems
- Tracer gas equipment
- Indoor climate analyzer
- Data acquisition equipment for measuring thermal and moisture conditions of rooms and constructions.
- Guarded hot plate apparatus for determination of thermal conductivity
- Indoor test facility for Solar heating storage tanks
- Particle Image Velocimetry (PIV) and Planar Laser-Induced Fluorescence (PLIF) for flow measurements
- Outdoor test facility for measuring solar transmittance
- Outdoor test facility for solar collectors
- Test facility for side-by-side test of vacuum tubular solar collectors
- Test facility for solar heating systems supplying domestic hot water
- Test facility for solar heating systems for combined heating and domestic hot water
- Outdoor weather station

Overview of test hall

Artificial sun

 Cold and hot box chambers	 Test facility for solar heat storage tanks
 Outdoor test stand for weatherization test of roof tiles	 Test stand for vacuum tubular solar collectors
 Outdoor test cells for test of hygrothermal room performance and test of daylight control systems	 Weather station

3.4 Publications

3.4.1 Research reports

Research reports from the Section for Building Physics and Services can be found under and downloaded from http://www.byg.dtu.dk/Forskning/hentned.aspx where they are listed along with other reports published since the year 2000 from the Department of Civil Engineering.

Reports for the period 1996 - 2000 from the Department of Buildings and Energy can be found and downloaded from http://www.byg.dtu.dk/Forskning/hentned/IBE.aspx

Finally, reports from the Thermal Insulation Laboratory from before 1996 can be found under http://www.byg.dtu.dk/Forskning/hentned/LFV.aspx. Most reports are available in a scanned digital edition from that site.

3.4.2 Journals articles and conference papers

Journal articles and conference papers are registered in DTU's research data base: orbit.dtu.dk

4 Teaching activities

4.1 Overview of courses and educations

11111 - Building Energy

11738 - Building Energy Design

11937 - Basic building design with regard to indoor environment, services and energy (1)

11112 - Technical Building Services 1

11739 - Technical Building Services

11947 - Basic building design with regard to indoor environment, services and energy (2)

11121 - Thermal Building Physics

11127 - Sustainable heating and cooling of buildings

11115 Building energy and technical services - Integrated design

11117 Solar Heating Systems

11119 Energy End-Use Savings and the Environment

11120 Daylight in buildings

11122 Heat and mass transfer in buildings

11982 Integrated Functional Project

11116 Sustainable Buildings

11125 Development of solar energy systems

11118 & **11615** Numerical Methods for Building Energy Technology

11126 Lighting Systems in Buildings

11124 Computational Fluid Dynamics on Buildings

11123 Experimental Methods in Building Energy and Indoor Climate

MASTER THESIS PROJECTS

COURSES WITH CONTRIBUTION FROM SECTION FOR BUILDING PHYSICS AND SERVICES

11000 - Engineering work
11080 - Advanced Building Design
11305 - The Finite Element Method
11691 - Project work - Bachelor in Building Technology
11701 - DesignBuild
11761 - Laboratory Course
11762 - Civil Engineering Design
11945 - Sustainable building design
11968 - Optimization, resources and environment
11969 - Optional project

4.2 Examples of student projects

4.2.1 Examples of teaching in building energy and building services

Design and Control of LED-based Lighting Systems for Office Buildings

Master thesis: Kristín Ósk Þórðardóttir, supervisor: Professor Svend Svendsen, Senior Scientist Carsten Dam-Hansen and PhD student Anne Iversen

Visual Comfort in Workingspaces – Focusing on Contrast Ratios

Master thesis: Ulrik Pedersen, supervisor: Professor Svend Svendsen and PhD student Anne Iversen

Introduction

These two master thesis's both investigates the (light emitting diode) LED technology as an artificial lighting source for office buildings to achieve lower energy consumption while maintaining the requirements for lighting comfort on the workplaces in a typical office buildings.

Design and Control investigates the LED lighting with individual control of the lamps for the best possible lighting scenarios for each desired task. A lighting system based on uniformly placed LED spots in a ceiling is designed. An extra feature of adding artificial lighting to the building simulation program *BuildingCalc/LightCalc* owned and design by DTU-BYG is made. With this feature it is now possible to model rooms with luminaires with daylight calculations and simulate the illuminance behaviour. Controlling strategies are also implemented to the program, which makes it possible to analyze the efficiency of the lighting planning design with various controlling techniques.

Visual comfort examines whether variations of light in an office, affect people's working efficiency and impressions/experience of the office. By using LED lighting with small and numerous spots located across the ceiling, the light can be regulated to illuminate the area around the workstation, while the surroundings have a lower illumination. A test is conducted to examine the effect of changing the contrast ratio in an office. Twenty persons are test subjects and have to solve typical office tasks and evaluate how they experience the lighting.

Using LED technology gives the opportunity to take advantage of the low energy of the LED light and reduce consumption of energy for lighting.

Simulations and Measurements

Three types of control were developed: Individual control where the aim was to maintain equally distributed illuminance level in the room, individual task light control where the aim is to keep a maximum illuminance level at the workplaces and regulate the rest down to a minimum and individual daylight control which gives the opportunity to regulate the artificial lighting after a predefined illuminance level if the daylight level are insufficient in the room, otherwise the lamps are turned off.

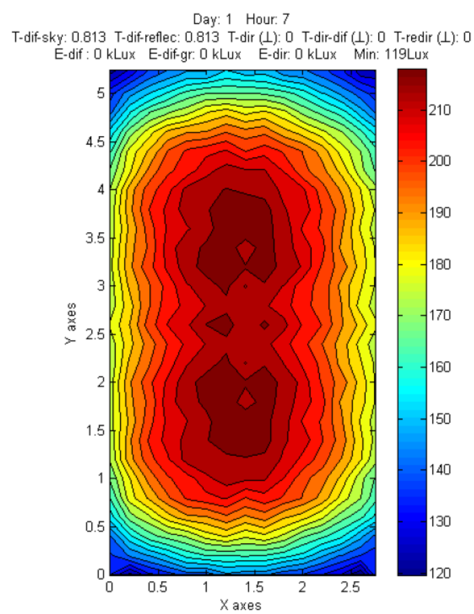


Figure 1: Simulation results from *LightCalc* with LED spots and individual control where the wanted illuminance level is *200 Lux*. The total installed effect without control is *9.6* W/m^2 and used effect after optimization is *6.1* W/m^2.

The first two controlling strategies can give a little over *30 %* in energy saving when controlled after a predefined illuminance level. The third control, (daylight control) gives the possibility of *75 %* in energy savings.

The measurements for testing the variation of light and the contrast ratio is set op as a test office so that it resembles real situation as much as possible. The test room is a small building located in DTU Byg test area. The room is ca. *15 m^2* with a large window facing south. The test room is set op as an office with one work station and 15 LED spot in the ceiling.

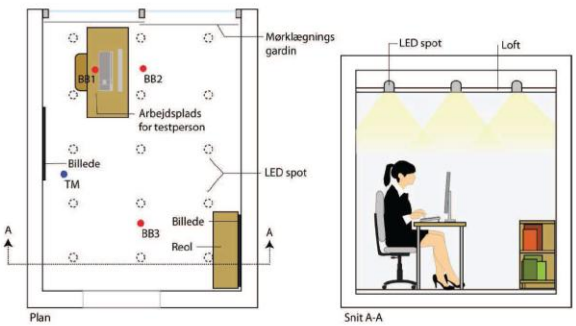


Figure 2: The layout of the test office

The affect of people's working efficiency is measured for four different lighting scenarios.

Belysnings-scenarie	Dæmpning af lyskilder				
	0 %	25 %	50 %	75 %	100 %
A	15	-	-	-	-
B	4	2	9	-	-
C	4	-	2	9	-
D	4	-	-	2	9

Table 1: Four lighting scenarios, the contrast ratio is varied by dimming the LED spot lights.

Belysnings-scenarie	Energiforbrug		Besparelses-potentiale
	[w]	[w/m²]*	[%]
A	144	9,8	-
B	80	5,4	44 %
C	59,6	4,0	59 %
D	41,6	2,8	71 %

Table 2: Energy consumption for the four lighting scenarios.

For small offices the energy consumption is typically between 8-15 W/m^2. Lighting scenario A with all lamps turned "on" fits well within the guided values. The illuminance value on the work desk does not vary allot between the lighting scenarios even though less indirect light is perceived from surrounding lamps due to lower illuminance in the room. The advantages of keeping the contrast ratio high can give energy savings of *44-71 %*.

It has been shown that too much and too low contrast ratio can result in bad indoor environment, such as tiredness and eye irritation. Therefore a solution with the right amount of contrast ratio results in a more positive experience, less eye irritation and tiredness. The measured efficiency of the test persons while solving the problems are not affected by the change in the contrast ratio as long as the illuminance on the desk is *200 Lux*.

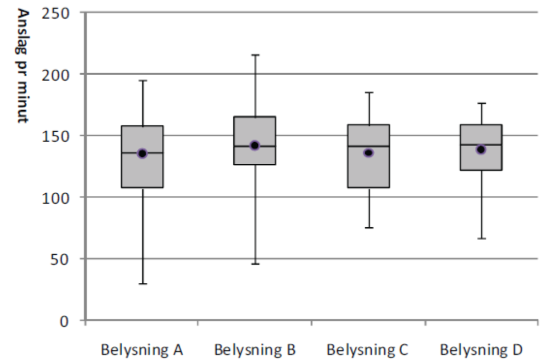


Figure 3: Evaluation of the typing task problem performed by the 20 test subjects.

By implementing many small LED spots in the ceiling gives big advantages and flexibility in creating the right contrast ratio.

Instead of downlights the LEDs can be turned upside down and mounted as uplights. This will reduce the perceived glare and the efficiency of the lamp can be increased by 48% by removing the optic of the lamp and using the entire radiation angle of the LED.

Results

Annual energy consumption of buildings can be significantly reduced by implementing energy effective LEDs and daylight control and therefore the demands of the EU to reduce CO_2 can be fulfilled. *BuildingCalc/LightCalc* gives the opportunity for the user to design a complete lighting solution with an advanced window system and optimized lighting, both to satisfy the need for illuminance level from daylight and the quality of artificial lighting.

The test shows that the working efficiency is not affected by changes in the contrast ratio. On the contrary, the test subjects tend to evaluate the lighting with moderate contrast ratio to provide less discomfort from glare and fatigue. The estimated annual energy consumption of the test office with 15 LED spots and a daylight control is *16.9* kW/a. The same room but with florescent lighting and daylight control is *40.5 kW/a* resulting in an energy savings of *58 %* of the LED lighting.

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Ulrik Pedersen *s032459@student.dtu.dk*

4.2.2 Examples of teaching in solar heating

Simon Furbo

Introduction

Theoretically, solar energy is the largest renewable energy source in the world as well as in Denmark. The annual solar radiation on Denmark's land area is about 180 times larger than Denmark's total annual energy consumption. Especially solar heating systems are of great interest.

Today four types of solar heating systems are used in Denmark:

- Solar domestic hot water (SDHW) systems
- Solar combi systems
- Solar heating plants for heating a whole town or a part of a town by means of a district heating system
- Air collectors for dehumidification of houses

Today simple financial payback times of solar heating systems in Denmark are 7-15 years, and merely by making technological improvements they can be halved.

Research and development in the field of small solar heating systems should concentrate on hot water tanks and interplay between solar collectors and other renewable energy sources. The development of larger systems should concentrate on solar collectors and seasonal heat storage.

A number of Danish manufacturers and companies are active on the European solar heating market. For example:

- Velux A/S markets solar heating systems in many European countries.
- Solarcap owns a number of Europe's largest solar heating companies.
- Arcon Solvarme A/S has produced large solar collector panels for about 50% of Europe's solar heating plants.
- Sunarc A/S produces antireflection treated glass for a large number of Europe's leading solar collector manufacturers.
- Chromecoat A/S produces selective coating for absorbers for a number of European solar collector manufacturers.
- Grundfos A/S produces circulation pumps for many solar collector manufacturers of the world.
- Solarventi A/S markets patented air solar collectors for summer houses with great success.

In the future, a considerable part of Denmark's energy demand can be covered by solar heat. As appears from the figure below, even now solar heating systems and wind energy systems are the most important types of renewable energy systems internationally.

At present, worldwide, the solar heating market grows by more than 30% a year, and the growth is expected to continue. If Danish companies are to continue to benefit by this large market, they must be able to offer products and services of high quality. This requires well-trained employees with expertise in the solar heating field, so that products and services of the companies can be based on the newest research in the field.

Department of Civil Engineering offers education in the solar heating field:

The course 11117 Solar Heating Systems treats the basic principles of solar heating systems for domestic hot water systems, solar combi systems and solar heating plants. At the course 11125 Development of solar energy systems course participants work on development of solar energy systems or components for solar energy systems.

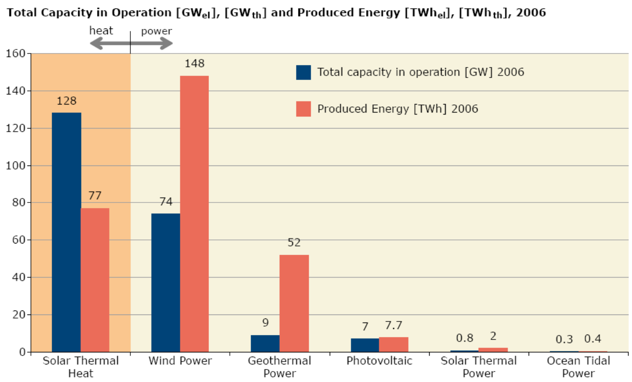

Figure 2: Total capacity in operation [GW_{el}], [GW_{th}] 2006 and annually energy generated [TWh_{el}], [TWh_{th}].
Sources: EPIA, GEWC, EWEA, EGEC, REN21 and IEA SHC 2008

Installed capacity and energy production worldwide for renewable energy systems.

Furthermore, special courses, diploma projects, bachelor projects and master thesis projects in the field can be carried out, for example in connection with the Institute's research and development projects. The student assignments can be carried out in collaboration with manufacturers of components or whole solar heating systems. There are many exciting student assignments to work on. Examples of previously completed and ongoing student projects:

2009

Andrea Bendotti, Master Thesis project: Heat storage with inlet stratifiers.

Gabriella Kónyová, Master Thesis project: Investigations of marketed solar heating systems.

Anne Pedersen, Master Thesis project: Investigations of marketed solar heating systems.

Jørgen Jonas Jensen, diploma project: Large solar heating systems in Greenland.

Daniel Trier, Master Thesis project: Control strategy for solar heating plants.

Jens Fogh Andersen and Lasse Juhl Pedersen, diploma project: Solar transmittance for glass.

Ivan Blom, Master Thesis project: Large solar heating system for Aalstruphus.

Ann-Mari Lanty Johansen, diploma project: Life time for solar collectors.

Maria Harrestrup, diploma project: Efficiency and lifetime of HT collectors.

Maarten Winter, special course: Advanced solar combi systems.

2008

Roberto Gimenez Mata, Master Thesis project: Inlet stratifiers for solar tanks.

Christian Chrom Starhof and Lars Erik Overbye, diploma project: Self supported glass façade.

Lasse Ingeman Michaelsen, special course: Solar radiation in Greenland.

Maria Harrestrup, special course: Solar radiation in Greenland.

Jørgen Jonas Jensen, special course: Solar radiation in Greenland.

2007

Martin Morelli, Master Thesis project: Heat of fusion storage for solar heating systems.

Lorenzo Iacovone, Master Thesis project: Solar combi system.

Pedro Cordeiro, Master Thesis project: Solar heating systems in Portugal.

2006

Diana Lauritsen and Katrine Flarup Jensen, midway project: Reflection from snow.

Rikke Jørgensen and Janne Andersen, Master Thesis project: Evacuated tubular solar collectors.

Anneli Carlquist, Master Thesis project: natural gas/solar heating system.

Mette Jensen and Louise Hedelund Sørensen, bachelor project: Solar transmittance of antireflection treated glass.

Asger Nøhr Ahmed, bachelor project: Solar energy for desalination.

Dennis Otieno Dyhr, midway project: Solar energy for desalination.

2005

Lars Lehn Rasmussen and Camilla Dyring, midway project: Evacuated tubular solar collectors.

Katrin Zass, Master Thesis Project: First functionality tests of the prototype of a new developed solar combisystem.

Antonio Maria Cravo, Master Thesis Project: Design and analysis of a sustainable building in Portugal with solar heating system.

Maite Butragueno, Master Thesis Project: Thermosyphon solar charging unit.

Daniel Garcia Barandalla, Master Thesis Project: Monitoring of a solar combisystem prototype.

Fredrik Emil Nors and Daniel Trier, special course: Advantage of antireflection treatment of PV modules.

Judit Zatyko, special course: Solar collectors for solar heating plants – theoretical investigations.

2004

Hongwei Li, Master Thesis Project: CFD investigations on inlets for hot water tanks.

Judit Zatyko, Master Thesis Project: Solar radiation from Greenland.

Karin Dyhr Andersen, Master Thesis Project: Advanced solar heating systems.

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4.2.3 Examples of teaching in building physics

Carsten Rode

Hygrothermal microclimate behind furniture against outside walls

Masters project by: Jeff Mertens.

Jeff Mertens is himself from Belgium but in 2005-06 he made his Masters project as a visiting student with our group at DTU. He worked together with Ph.D.-student Lone H. Mortensen to study the hygrothermal and air flow conditions behind furniture which is located against a cold wall – a typical location for high humidity. Particle image velocimetry (PIV) was used to measure the air flow in the air gap behind the furniture. Thermocouples, RH sensors and special developed humidity cups were used to determine the local condition of temperature, humidity and surface moisture transfer coefficient over material surfaces which are in contact with air in the gap.

Sketches and a picture illustrating how PIV equipment was used to measure air velocity between a piece of (superficial) furniture and a cold wall.

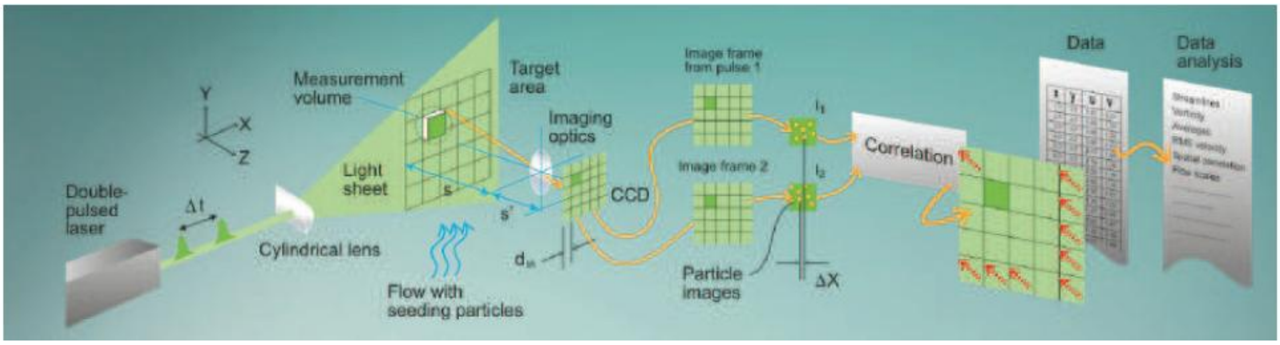
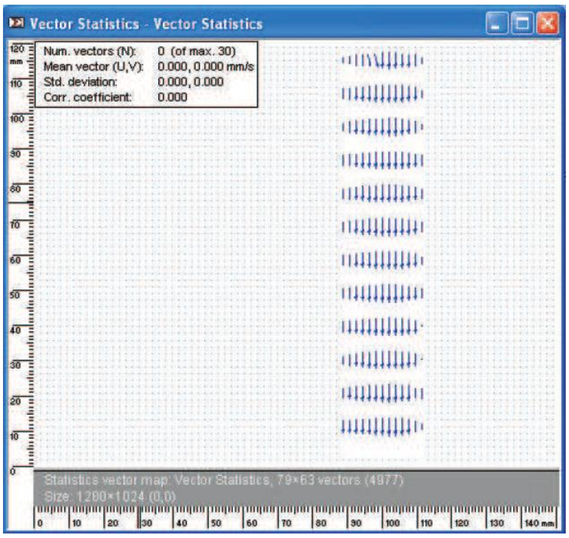
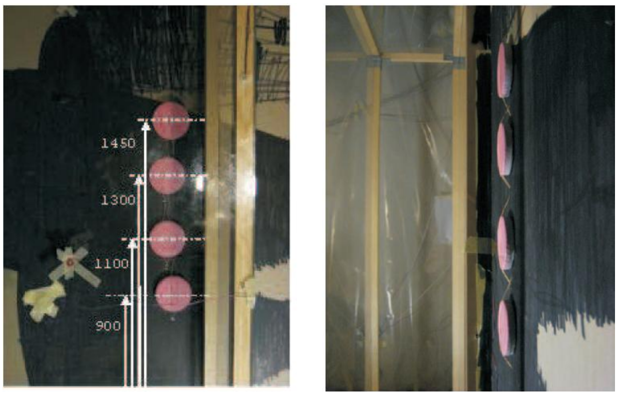


Illustration of how pulsation laser beams are used in Particle Image Velocimetry equipment to trace the movement of particles along with the stream of a fluid – in this case air.



Measured velocity vectors for air in the gap behind the furniture.



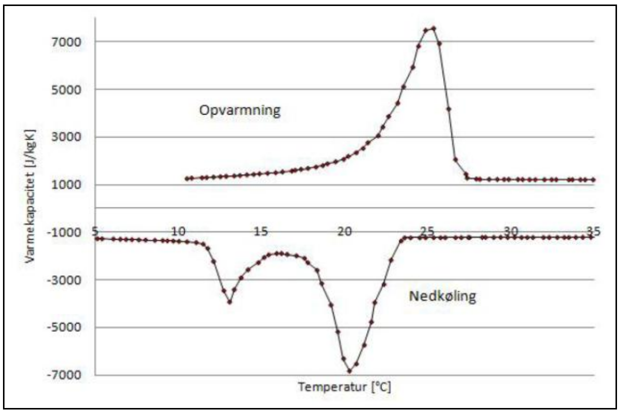
Shallow petri dishes filled with desiccant and with (pink) paper as lid were used to measure the surface moisture transfer coefficient.

Temperature stabilization with phase changing material

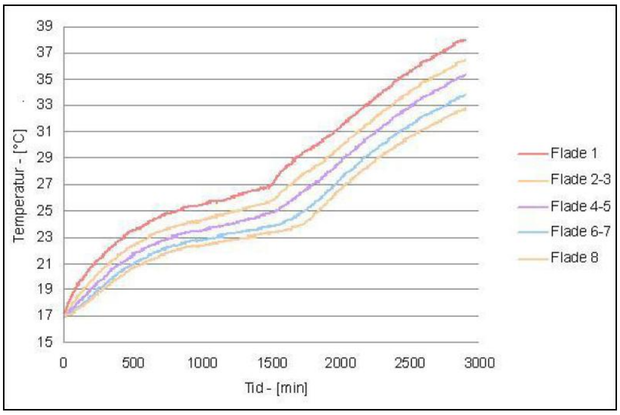
Bachelors project by: Amalie Gunner & Simon Sigurd Henriksen.

Phase Change Materials (PCM) can be used to enhance the apparent thermal capacity of building materials and thereby result in smaller temperature variations in rooms where such materials are used. When the temperature passes the melting point of the paraffin that is the main constituent of PCM, the material takes up the melting heat while the temperature remains almost constant. Likewise, during cooling, the heat is released again when the material solidifies at almost constant temperature. Thus, overheating should occur less frequently in rooms which have high heat gains in daytime if the walls are clad with PCM material. Investigations were carried out in this project of a particular gypsum board product from Knauf Danogips which contained BASF Micronal phase change material. The following investigations were carried out for the product:

- Determination of thermal conductivity
- Determination of specific heat
- Temperature variation in a stack of PCM gypsum boards
- Temperature variation in a test chamber clad with PCM gypsum boards

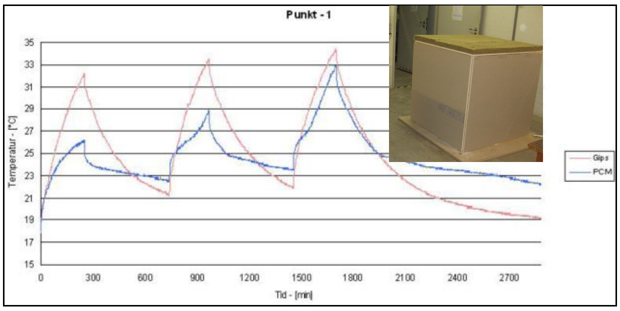


Specific heat of PCM gypsum board measured with DTU Byg's micro calorimeter both during a heating and a cooling process.



Temperature variation in a stack of PCM boards when the temperature is excited. The variation is delayed while the phase transition takes place around 23°C.

Small test chamber to measure inside temperature variation using different wall claddings. Size: almost 1 m^3.



Temperature variation in the test chamber when there is an intermittent heat source in the chamber. Red curve: with standard gypsum cladding; blue curve; with PCM gypsum cladding.

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5 Research activities

5.1 Research activities in Building Energy and Building Services

The goal of the research on building energy and building services is to create new knowledge of the process and product side of the development of buildings, which is an important element in a sustainable development. The aim is to develop knowledge of new or improved types of building envelope design, window systems, and building services, which can make complete buildings independent of energy supplies from fossil fuel. The research deals with methods for characterization of building units, services and properties of buildings with reference to development, design and optimization of these with regard to indoor climate, functionality, energy consumption and life cycle cost.

Research into *building energy technology* is oriented towards methods for integrated design and optimization and product development of low-energy buildings with a focus on comprehensive treatment of the buildings' overall indoor climate conditions, gross energy and total economy. Research is augmented by the construction of models and programs for calculating the energy characteristics of components and whole buildings. These models form the common basis for development of new low energy buildings and renovation of existing buildings to low levels.

Research on *building services* focuses on the construction of detailed models for systems for ventilation, heating, cooling and lighting in buildings and the associated energy supply systems. New models include the simulation of electricity saving ventilation with heat recovery, demand controlled ventilation systems, electricity saving lighting controls, and air conditioning for low buildings. It enhances the understanding of the functioning of new types of energy efficient and intelligent building services and heating systems.

Successful Sustainable Renovation Business for Single-family Houses – SuccessFamilies

Nordic Innovation Centre Project (2009-2012): VTT (Finland) in cooperation with DTU Byg, Mid Sweden University and Segel (Norway)

Introduction

Energy renovation of existing buildings has a large potential for cost effective energy savings. However, it is a major challenge to develop and implement the technologies for reducing the energy use in existing buildings to a very low level in combination with renovation of the buildings. New solutions are needed also on the technological side, but more importantly, for the business environment.

Residential buildings are responsible for 70 % of the energy use in buildings in the Nordic countries. In all Nordic countries single-family houses constitute a large part of the building stock, and offer big business opportunities for renovation services.

There is a substantial lack of business concepts for renovation services for single-family houses, whereas the multi-family houses are better covered. Also, in e.g. Finland and Sweden, most of the apartment buildings are connected to a district heating network, which mostly uses the waste heat from electricity production, whereas most of the single-family houses use other sources for heating, thereby offering a better possibility for CO2 reductions.

Background and earlier studies

Previous studies conducted by the participants have shown that energy optimization has to be done in connection with traditional maintenance and other changes of the building in order to be cost-effective. Furthermore, it has been pointed out that opportunities for thorough improvements of the building envelope and technical installations occur with a long interval so it is of utmost importance not to miss these opportunities by making a renovation without upgrading the energy performance of the specific building component up to, and preferably beyond the current requirements in the building code.

A Danish energy renovation project has proven that it is possible to renovate a typical Danish single-family house from the 1960/70's in a cost efficient manner to roughly the energy performance standard of a new single-family house. As a positive side effect the living conditions have been greatly improved. Many similar examples are presented in ongoing work of the IEA SHC Task 37, which both VTT and Segel AS are participating.

About half of a total of 1.1 million Danish detached single-family houses were erected in the 1960/70's, so applying the same renovation technologies to that part of the building stock would offer big possibilities for energy saving on one hand, and renovation service business on the other hand. Also in Finland there is a typical single-family house, the so called Veteran house, which was a largely applied building concept after the second world war, in 1940's and 50's. Similar groups of typical single-family houses can be identified in all the participating countries, where standard technical solutions and new service concepts can be developed.

Objectives and Solutions

The main objective of the project is to change the business environment in order to speed up the implementation of sustainable renovation of single-family houses.

The resulting new service concepts will combine both the technical solutions, financing services as well as other promoting issues to overcome the behavioural, organizational, legal and social barriers that exist in sustainable renovation.

Off-the-shelf renovation service packages

The solution to the lack of business concepts for renovation services for single-family houses is first of all that renovation service packages should be developed to include standard technical solutions for energy efficiency improvements regarding different building systems and ages. Secondly, all other necessary services should be included, providing overall renovation solutions for the people living in single-family houses.

Providing off-the-shelf renovation service packages will significantly improve the quality of life for many single-family house owners. This kind of concepts would not only improve the energy efficiency and IEQ (Indoor Environment Quality), but they would also provide an economically viable and easy-to-get choice for the house owner. Making the energy-efficient renovation services easy-to-get will speed up the implementation of energy efficiency improvement measures.

The new services must be supported with new features, like better visualisation, guaranteed price and funding services to overcome the behavioural, organizational, legal and social barriers that exist in sustainable renovation.

Work Pakages

The project will be divided into five Work Packages (WPs):

WP1. Sustainable renovation concepts

WP2. Marketing strategies for sustainable renovation

WP3. Successful service models

WP4. Dissemination

WP5. Coordination

The project will develop the technical concept solutions, and strategies on how to sell and implement sustainable renovation of single-family houses.

The project is a part of a Joint Nordic Call of Sustainable Renovation. The partners of the project are VTT Technical Research Centre of Finland, Danish Technical University (DTU) Civil Engineering - Building Physics and Services (Denmark), Segel AS (Norway) and Mid Sweden University.

The main target groups for the project results include: single-family house owners, insulation material firms, banks, heat pump providers, lighting manufacturers, pipework & ductwork providers, hardware dealers, ESCOs, energy suppliers, etc.

Energy savings potential

As a basis for the project work a review of existing building stock analyses in the Nordic Countries will be made aiming at identifying the typical houses with the greatest energy savings potential that can be found for different time periods.

Danish energy savings potential

The most recent and thorough Danish investigation of the savings potential in existing buildings was conducted early 2009 by Aalborg University, Danish Building Research Institute, AAU-SBi (Wittchen 2009). This investigation is based on information from public building data files and most recent issued building energy certificates (2005 until late 2008).

Different scenarios were investigated, called "obvious", "healthy" and "extreme" measures respectively. The results of the scenario calculations regarding building envelope constructions are shown in Table 1. It shows that In general the savings potential is especially great for houses erected before 1979 (before the second oil crisis), due to the poor energy requirements in the building code.

The greatest energy savings potential is in old farmhouses, and especially in detached master builder houses from before 1930 and small detached standard houses from the 1960's and 70's.

Table 1: Energy savings potential (space heating) in TJ/a by implementation of building envelope measures in Danish single-family houses (Wittchen 2009). The heating consumption in Danish Single-family house is approx. 96 PJ/a.

	1850-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	Total
Scenario: "Obvious"							4,537
Farm houses	770	113	20	29	4	7	943
Detached house	1,123	477	417	874	152	56	3,099
Row houses	163	124	65	93	43	7	495
Scenario: "healthy"							21,940
Farm houses	2,974	422	116	82	43	78	3,715
Detached house	4,802	2,273	1,987	3,840	1,638	872	15,412
Row houses	710	392	320	385	314	692	2,813
Scenario: "extreme"							36,100
Farm houses	5,085	729	230	101	87	120	6,352
Detached house	8,412	4,328	3,738	4,667	3,144	1,252	25,541
Row houses	1,142	647	558	475	557	828	4,207

The energy savings potential regarding better efficiency of heating systems including boilers etc. is estimated at 16 PJ/a, of which 0.4 PJ/a is electrical consumption. The investigation shows that if the "obvious" scenario is disregarded, the total savings potential of energy for heating is in the range of 40-60 %. This is a conservative estimation because ventilation with heat recovery is not taken into account.

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Integrated design of new low-energy office buildings

Ph.D. project: *Steffen Petersen*

Background

The objective is to develop and test an integrated design method for design of new office buildings with low energy consumption and good indoor environment with a reasonable total economy. The suggested integrated design process is seen in figure 1.

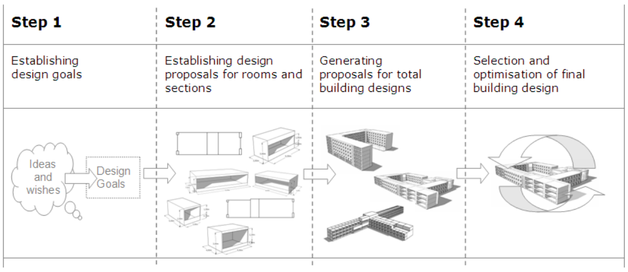

Figure 1: A simple description of the total integrated design process.

The process is based on design of rooms before buildings since the quality of indoor environment is related to rooms. Following this process the designer is able to generate design proposals which facilitate the performance requirements regarding energy consumption and indoor environment.

Methods and tools

A method for facilitation of step 2 is suggested. The idea is to enable building designers to make consequence-conscious design decisions. The workflow of the suggested method is illustrated in figure 2.

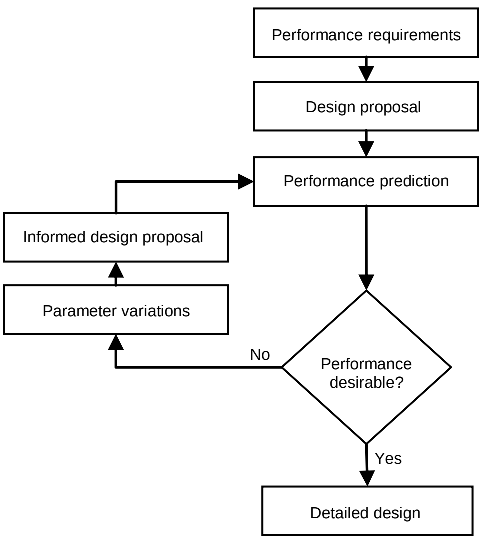

Figure 2: Workflow of suggested method to facilitate step 2 of the suggested design process.

The parameter variations which constitute the basis for informed design decisions are performed in a simulation program called iDbuild. The output of a parameter variation is illustrated in figure 3, 4 and 5.

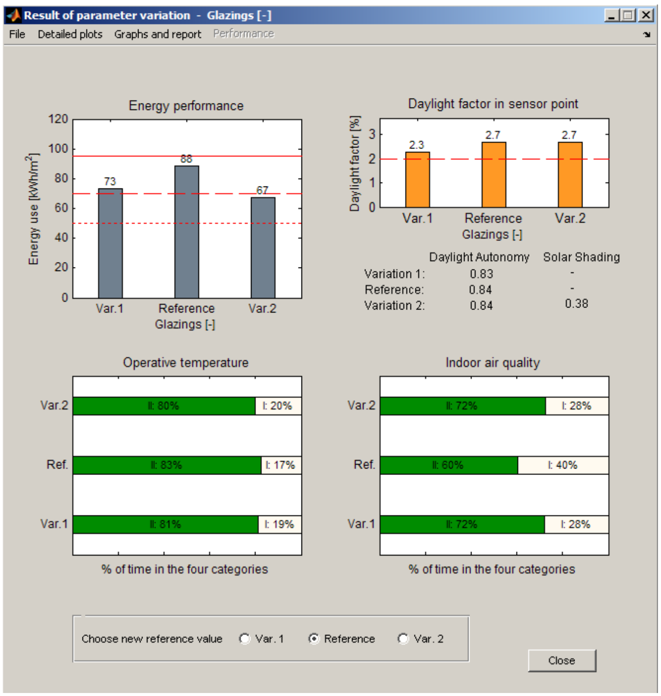

Figure 3. Result from variation of glazing component in a 2-person office.

Figure 3 illustrates the summary of results from a variation of the glazing component in a 2-person office. 'Var. 1' is a 2-layers with solar coating, 'Reference' is 2-layers with standard energy coating, and 'Var. 2' is a 2-layers with standard energy coating with external, white blinds. Figure 4 illustrates the detailed energy output.

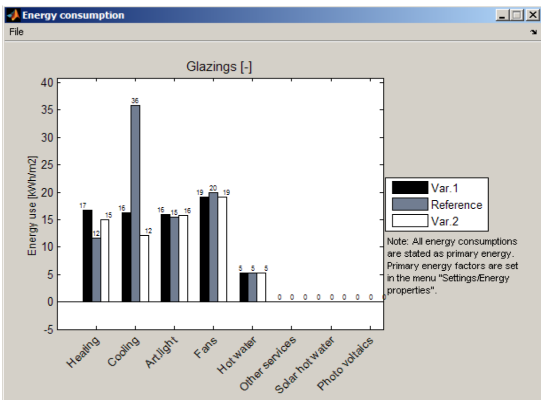

Figure 4. Detailed energy output from variation in figure 4.

Figure 5 is an analysis of the annual daylight performance for the parameter variation of the glazing components from figure 3. The hourly daylight levels in lux are plotted for each month. The red areas indicate hours with a daylight level above 500 lux.

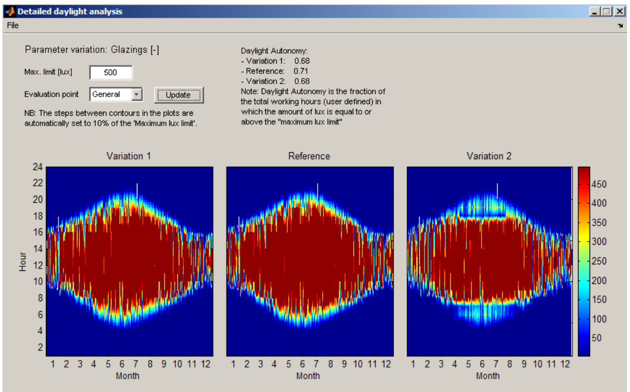

Figure 5 Analysis of the annual daylight performance for the parameter variation of the glazing components from figure 3. The hourly daylight levels in lux are plotted for each month. The red areas indicate hou with a daylight level above 500 lux.

The output of a parameter variation like in figure 3, 4, and 5 enables the designer to understand how design decisions affect performance requirements regarding energy consumption and quality of indoor environment before any actual design decision is performed.

Preliminary results

The process, method and simulation program are tested in a case study which is a part of an undergraduate course at DTU. Based on the student feedback from these tests, the method is reviewed and developed. This procedure is repeated annually in a period of four years resulting in an iterative refinement of process, method and tool.

The main conclusions from the tests of the process, method and simulation program is: 1) the design process consistently leads to low energy buildings with high quality of indoor environment, 2) whether the process is a success very much depends on the usability of the simulation program, and 3) the suggested process should be considered as an important analytical exercise in the building design process rather than a way of designing buildings.

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Integrated design of larger buildings

PhD research project

Introduction

Start date: September 2008

Completion date: September 2011

A growing awareness of possible anthropogenic climate change has led to increased demands for developers and designers to design buildings with a more sustainable profile. To design cheap energy efficient sustainable buildings with a good indoor climate, it is necessary that one can foresee the different interactions existing between the design, energy-use and indoor environment. By looking holistically on the energy consumption in relation to design and by increased integration and a wider use of a dynamic design process - knowledge about building physics can be used to develop a new type of architecture - which is generated by a technical, scientific understanding of building physics and design.

The study topic is to identify the dynamic interactions that exist between building physics and practical design choices such as geometry relationship, component and system solutions, and on this basis develop methods to improve the design process by making it more informative with respect to resulting energy-use, indoor environment and total economy.

In order to use the dynamic interaction between the architectural and engineering design process in the development of sustainable buildings, there is a need for a new method that allows the engineers input to influence an emerging building design. But the architects early design process is a quick and dynamic process, where there is often not time to perform time-consuming whole building simulations, and therefore is there a need for a new tool, which is dynamic and fast to use and that can perform parameter analysis of different design choices.

The project's hypothesis is that the dynamic interactions that exist between building physics and different geometry, component and system solutions quickly can be identified and that it is possible to develop an improved model which is faster and more informative in relation to energy-use and indoor environment. With the formulation of a model, based on hourly weather data, contextual factors, it can be used to calculate yearly values for the indoor environment and energy-use for specific geometries. The method is currently based on rooms, but can be developed to include entire buildings and the perspective is that the model with the design of a representative reference model can assess urban properties in relation to energy and indoor environment.

The aim is that the method and model will serve as an "intelligent" and helpful tool for designers in the creative design process on the basis of dynamic analysis of different design choices, to guide designers through the first stages of the design process. The method should give the architect an idea of how the specific design choices are associated with the building's total energy consumption, i.e. when you dynamically change the building's geometry or system the model provides an output of energy-use, thermal environment, indoor air quality and daylight.

Thus, the aim is that the methods and tools will be seen as a helpful means for designers. Thus the method can be included and enhance the creative process through a better understanding of the dynamic relationship between buildings physics and different design choices. The method tested in different projects with Henning Larsen Architects, thereby providing the opportunity for evaluation and development of the methodology and model during the project period.

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Integrated energy design in masterplanning

PhD project: Jakob Strømann-Andersen in collaboration with Henning Larsen Architects
Start date: October 2008 - Completion date: September 2011

Summary

The research project's overarching subject is to develop technical scientific methodological assessment tools, that the architect in early design stage can qualify the formative basis for making decisions with respect to energy-efficient solutions, as a basis for future town planning and building design.

The research operates with two parallel hypothesis formations, representing the intuitive creative (architect) and technical scientific (engineer).

1. Can technical scientific impact assessments of micro-climate and energy flow in urban space serve as a tool in the design of the urban geometry?

2. Is it possible to link daylight and solar radiation, delivered at the façade depending on the shade of the building itself and its surroundings together with the illumination level in the room, and thus energy and daylight performance for the building?

Fig. 1: The projects are sponsored by the foundation Realdania and carried out in collaboration with Henning Larsen Architects.

Background

So far, the focus has been geared towards the optimization of the individual building and its various systems, operation, and maintenance. The individual building's design and specific location in the context is always a result of the urban geometry. By considering building isolated from the city's context the interaction between environment and building energy performance is ignored. The future challenge is to consider the urban geometry and buildings in an energy correlation and use the knowledge to design energy-optimized cities and buildings.

Energy consumption for building and the city's urban elements are now two unrelated sizes. Overall, simulation models are not integrated in the early planning stages, because it has been customary to leave the building physics to the design of each building.

Hypothesis

The project's hypothesis is that it is possible to qualify the resolution for the design of future cities, neighborhoods, and buildings from technical scientific sustainability analysis. It is also the project's hypothesis that by using such a method would ensure that the urban geometry has a positive impact on the building's energy performance.

The study is a morphological study; the only parameters that will be taken into consideration are the parameters that are related to the urban geometry. The project does not have a complete diagnostic target. The goal is not to provide exact figures on energy consumption at the urban level, but to establish comparable values that dynamic can be used in an integrated design process.

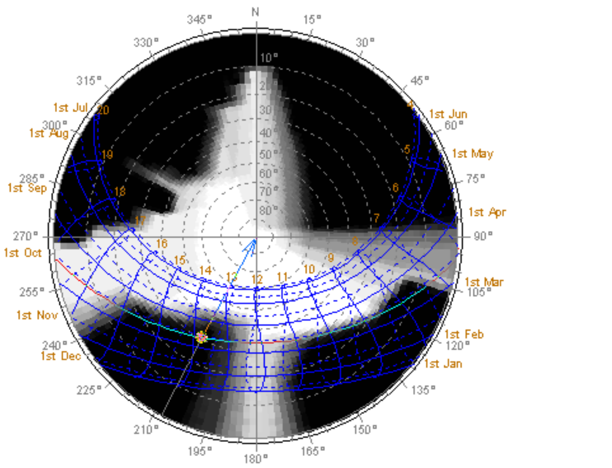


Fig. 2: An example surface shading mask mapped onto a stereographic sun-path diagram.

Science

Scientific are the project entering a new and so far uncultivated area where technical scientific analysis of the energy interaction between the urban geometry and the individual building's performance is used as a tool in an integrated design process.

The method relies on the use of existing calculation programs that can perform thermal simulations as well as daylight simulations. The method turns around the normal way of thinking and sets ground rules for the urban elements: street, square, blocks, etc. in relation to domestic energy in the building.

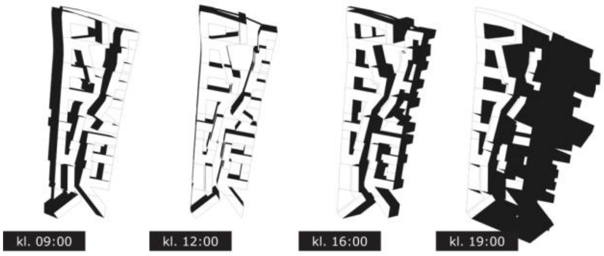
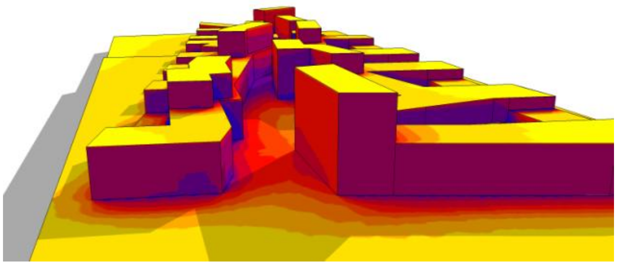


Fig. 3: Shadowrange 22th june, Carlsby Masterplan project

The project works in the way of a holistic technical scientific view of urban and buildings that provide entirely new energy options, because the effect of e.g. shadows from surrounding buildings can be taken into account, like impact of wind and daylight conditions from different urban landscape designs. What is new is to move from good intentions and strategies to actually be able to make calculations, which may constitute rules for design of the urban geometry in connection to the energy efficiency of individual buildings.



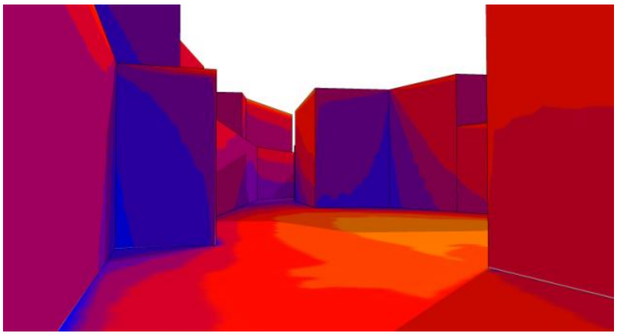


Fig. 4: Incident Solar Radiation on building surfaces in Carlsby, Masterplan. (Direct and diffuse solar radiation).

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Integrated Energy Design of the façade

PhD. project: *Martin Wrå Nielsen*

Summery

The research project deals with integrated design of future low energy buildings with the performance of the building facade as a focal point. The main objective is an implementation of technical scientific knowledge in the early design stages in order to qualify the design decisions regarding energy efficient facades.

Background and motivation

The *Intergovernmental Panel on Climate Change* (IPCC) emphasizes the gradually widely accepted fact that emission of greenhouse gasses results in global warming [IPCC, 2008]. This increases the demand for active participation in reducing man-made carbon dioxide emission through reduction of the use of fossil fuel and thus creating a new reality beginning now [Brundtland, G.H. et al., 1987].

The project seeks to participate in the establishment of a new reality through the enhanced focus and good will, which are also found in the building industry, where phenomena like energy optimization and sustainability are given increasingly more attention. In order to obtain energy efficiency in the building industry it is, however, necessary to consider a problem with various decisive parameters of high internal dependency and complexity [Wilde, P. de, 2004]. The interaction between design, energy and indoor climate thus adds a need for technical knowledge already from the very early stages of design, so that problems and possible synergetics may be disclosed. In this regard, the challenges of energy consumption and indoor climate have become decisive parameters in both new and existing buildings on international plan [EPBD, 2002].

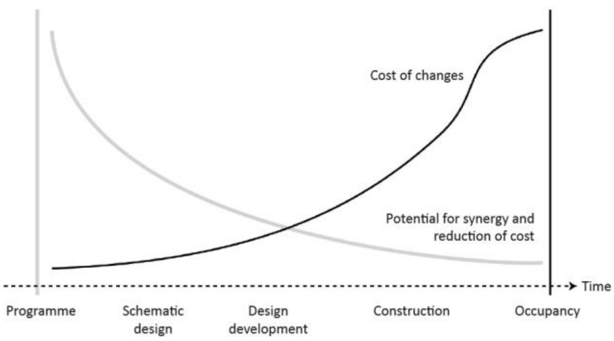

Fig. 1: The effect and the cost of design alterations change throughout the design process. The later the change is implemented the lesser effect and the greater the cost [Löhnert, G. et al., 2003].

Objectives and Methodology

The hypothesis of this project states that with the implementation of technical scientific knowledge it is possible to qualify design decisions of the facade. Furthermore it is estimated that a large potential remains in the consideration of the dynamical possibilities of the facade and its adjustment to a given variation in user pattern and outdoor climate. A larger degree of potential adjustment and adaptability will make it possible to exploit the present resources of daylight and solar heating more optimally. This can be achieved through investigation of solar screening solutions and climate dependant control, the design of windows, variation in the degree of insulation and the connection between the facade and the buildings HVAC-systems (Heating, Ventilation and Air Conditioning).

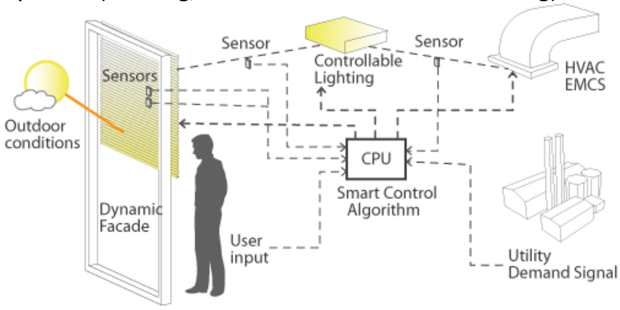

Fig. 2: Relational chart showing how both internal and external input defines the control strategy for the components in the dynamic façade [LBNL, 2008].

Through this, the interaction of the total energy consumption of the building and the quality of the indoor climate is optimized in considering the many conflicting aspects of a good facade design.

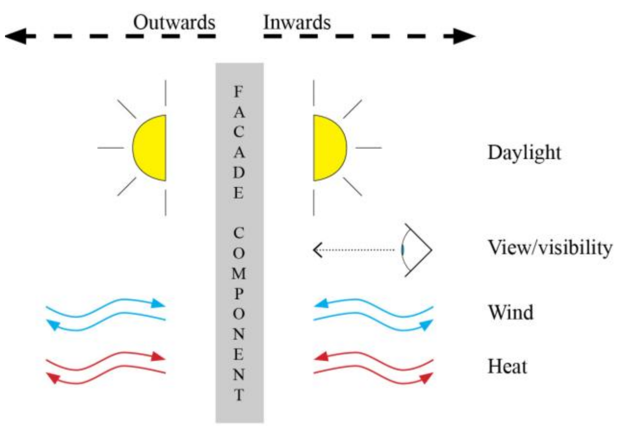

Fig. 3: Simple illustration of the conflicting aspects for a single façade component.

In collaboration with architects, a dynamical facade can become a source for a development within aesthetics and design in the given project and a constant supply of technical and engineering knowledge can thus function as the direct design facilitator and ultimately securing well-informed choices (see *Fig. 4*).

Fig. 4: The Showroom for Kiefer Technic shows an example of a dynamic façade and its possible influence on the over-all aesthetic appearance.

Architect: Ernst Giselbrecht + Partner ZT GmbH
www.giselbrecht.at

State-of-the-Art is established regarding methods of design and models of calculations within the area. On the basis of that, methods for integrated design of facades, which can be implemented directly into the iterative design process of architects, with subsequently a more optimal indoor climate and energy profile, are presented. According to the demands of the method, new models for calculation are established and implemented in simulation tools in order to identify the effect of the dynamical facades and their central role in energy efficient buildings of the future.

Anticipated results

Through simulations the project is expected to yield a method for decoding the significance of the façade with respect to energy consumption and the quality of the indoor environment. The method will be able to enter into a dynamic and interdisciplinary design process. This facilitates the possibility of benchmarking different façade designs and their performance in order for them to comply with both national [EBST, 2008] and international standards [CEN, 2006]. Here, the communication of the results is regarded with great importance in order to make sure that the relatively technical output can be implemented in the design process. Thereby, the results of this project will participate in meeting the increasing demands for reduction of the total energy consumption in buildings.

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3. of August, 2009

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Development of new energy windows of composite materials

Research project: David Appelfeld in cooperation with Svend Svendsen and Fiberline Composites A/S

Background

The energy consumption for the space heating of buildings was in 2007 about 40% of Denmark's total energy consumption, of which approximately 25% are assumed to be heat loss through windows. There is therefore a considerably energy saving potential in developing new and better low-energy windows both for use in renovation of the existing building mass and for use in new buildings. The project aims to drawn the foundation for the development of windows with a positive energy contribution and long service life in Denmark. This development will support both current and future (2010 and 2015) reinforced energy in building regulations. The key to fulfil these new energy requirements is the selection of the best available window components. The general goal of the project is to make the window an energy gaining component of a house and not as today an energy consuming component. The project will increase energy efficiency as an objective to help reduce C02 emissions and therefore have an influence on achieving the political objectives, including commitments under the Kyoto Protocol. Likewise made contributes to the objective of covering more than half of the electricity and district heat production from renewable energy in 2030.

Introduction

Project focus on the development of the window frame structures from composite materials for use in combination with different types of 2 and 3 layer energy glazing. Composite materials such as Glass Fibre Reinforced Polyester (GFRP), is a complex material, which is extremely suitable for window profiles, since it is light, strong and resistant to corrosion with low thermal conductivity. Through cooperation with GFRP profiles manufacturer Fiberline Composites A/S and several Danish window manufactures can be the product development of the GFRP window profiles supported and stimulated to develop generally applicable frame profile and complete window solutions of composite material. The intention is to have prototypes of the promising solutions. Proposed optimized solution should achieve maximum energy savings by reducing heat loss (U-value) and maximize solar gains (g-value). The challenge is to use composite materials in strong interaction with the glazing whilst making the frame narrow and neutral. The finished window frame must solve a series of technical problems, for example placing of hinges and fittings, and simultaneously be designed so that it is aesthetically pleasing.

Methods and Methodology

The project will be undertaken in close cooperation between BYG DTU, Fiberline Composites A/S and window m. DTU is responsible for supporting the manufactures during product development of new window frames made from GFRP by providing thermal calculation, particularly U-value and NEG. Fiberline Composite A/S is responsible for providing design of the profiles and especially production of GFRP.

Advising to the manufactures is by performing thermal calculation and optimize design base on these results in order to achieving best possible results with small heat loss through window frame, while profile is thin to maximize solar gains.

Material - GFRP

Glass Fiber Reinforced Polyester (GFRP) composite material by its thermal and mechanical properties is very suitable material for window, door and façade profiles. In particular it is low thermal conductivity; low weight, long life and zero maintenance are among the characteristics that give composite a strong environmental profile. The comparison with other materials used for window profiles are shown in Tab. 1.

Material	Thermal cond. [W/mK]	Lifetime	Strengths
Alum.	160	**Long** *(Cold bridges)*	High
Wood	0.13	**Short** *(needs maintenance)*	Low
PVC	0.17	**Long** *(needs reinforcement)*	Low
GFRP	0.25 - 0.32	**Long**	High

Tab. 1: Comparison of materials for window frames

Composites are defined as materials which consist of not less than two different component materials, neither of which are well suited for construction purposes on their own, but which in combination result in a very strong and rigid material.

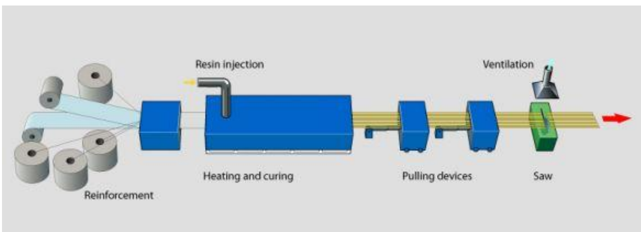

Fig. 1: Manufacturing of the composite profiles - Pultrusion

Calculation

The calculations are performed in program Therm and the results are used for calculation of U – value. In Denmark requirements in building codes are based on the net energy gains, therefore the g-value of window has to be also known.

NEG – Net Energy Gain

The net energy gain of windows is the solar gain minus the heat loss integrated over the heating season. The net energy gain in Denmark is calculated for an averaged over different orientations.

$NEG = gw \cdot I - Uw \cdot G$ [kWh/m²]

$NEG_{DK} = g_w \cdot 196.4 - U_w \cdot 90.36$ [kWh/m²]

Where:

g_w solar energy transmittance of the window
I total solar radiation in the heating season
U_w heat transfer coefficient (U-value)
G degree hours

The expression of the net energy gain for the Danish climate is based on the period from 24/9 to 13/5 (heating season) and the following distribution of the windows in a house; South: 41% , North: 26%, East/West: 33%.

Therm

By the programme Therm it is possible to analysis two-dimensional heat transfer through profiles, analysis is based on the finite-element method, which can model the complicated geometries of the profiles.

By obtaining U-value and graphical output of heat flux through a window frame profile it is possible to optimized the profile's design. Fig. 2 shows graphical output of the simulation of the window produced by PRO TEC Vinduer A/S. The frame is 57mm thin and the NEG of standard window is +7 kWh/m².

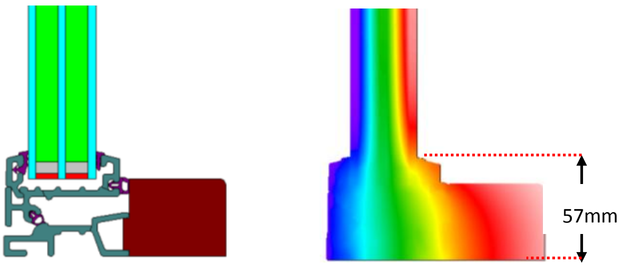

Fig. 2: Example of the Therm simulation of New Danish low energy window made from GFRP produced by PRO TEC VINDUER A/S

Anticipated results

This project will mainly stimulate and support the development of new types of energy window with positive NEG, since only few similar products have been developed during the last couple of years at Danish window market. Further the project will affect the development process by setting thermal models for performance modelling of windows. There is a great potential that the models will be tested and validated against the real full scale prototypes of the windows produced by the cooperating manufacturers. On Fig. 3 is shown the project aim for NEG of window. The expected results are that the NEG could be +20 - +40 kWh/m² and the thickness of the turn/tilt window frame reduced down to 40mm.

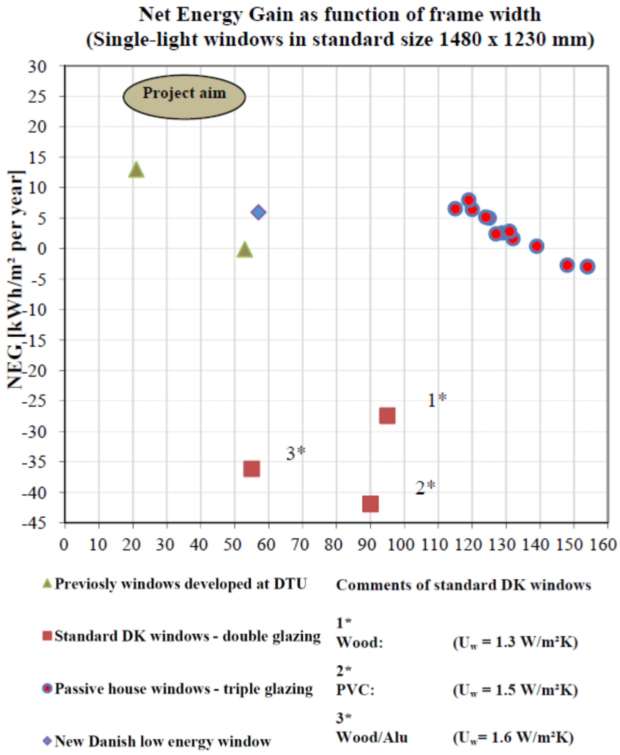

Fig. 3: Example of the NEG of window samples, including project aim.

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Program to Optimize the Selection of Windows in Dwellings: WinDesign

Research project and master thesis: Thorbjørn Færing Asmussen, Inês Santos, Svend Svendsen, Lies Vanhoutteghem

Introduction

Today, the reduction of energy for heating and cooling of buildings is an important field of research since the energy problems with respect to global warming, the depletion of raw materials and the rising energy prices are becoming a top priority problem that needs to be addressed and solved. The increase in energy efficiency is therefore a core element of political strategies and measures of the Member States of the European Union.

In the last couple of years, there has been made a number of initiatives according to the Energy Performance of Buildings Directive (EPBD) to lower the energy consumption of buildings, since they account for 40% of the energy consumed in the EU. To comply with the principles of the EPBD, the Danish Building Code introduced a so called `energy frame' that sets up requirements to the total energy consumption in buildings. In order to calculate the total energy consumption, the Danish Building research Institute introduced the software Be06. This program is based on the monthly averages as described in the standard EN 13790.

Calculation of energy use and indoor environment

In order to save a lot of energy in buildings due to heating, improved types of windows with lower heat loss and higher solar gain and can be used. Energy use for electrical lighting can be reduced by use of larger windows. In order to avoid overheating and energy use for cooling windows with solar shading systems may be used. In designing the windows of low energy buildings it is necessary to make calculations of both the energy use and the indoor environment. Hence, a new program to optimize the selection of windows in buildings, to be used by architects and engineers, has been developed at BYG.DTU. The program, named WinDesign, can be used during the design phase of new buildings or for the renovation of existing ones and is based on the requirements in the standard EN 13790. As the aim of the program is to be user-friendly, it is based on simple input data and accordingly it has been built in Microsoft Office Excel 2007 using built-in functions and User Defined Functions (UDF) programmed in Visual Basic for Applications (VBA).

Description of the program WinDesign

WinDesign is organized to select windows in four different stages, referred to as Step 1, Step 2, Step 3 and Step 4. However, the user is not obligated to follow the four steps although some of the steps require the previous ones to be done, see Fig. 1.

Fig. 1: Overview of the different steps in WinDesign

Step 1: Net energy gain of individual windows

In Step 1, different individual windows can be defined based on the knowledge of window geometry and components (glazing and frame), in order to calculate and evaluate U-value, g-value and net energy gain for each window.

Fig. 2: Graphical User Interface of Step 1

In order to define the windows, pre-defined classes of the frames and glazing can be used. However, the program allows more experienced users to define frame and glazing properties themselves and is thus flexible.

Step 2: Energy performance of windows in dwelling

In Step 2, a complete set of windows can be defined, or used from the previous step, for different rooms in a specific dwelling in order to calculate the energy consumption. For each window, the orientation, obstructions from the horizon, overhangs and fins and solar shading devices need to be defined. Up to five scenarios of windows for each room can be implemented. In order to calculate the energy consumption of the windows integrated in the dwelling, information about the dwelling, such as UA value, thermal mass, internal gains, ventilation and heating and cooling set points, needs to be included, see Fig.3.

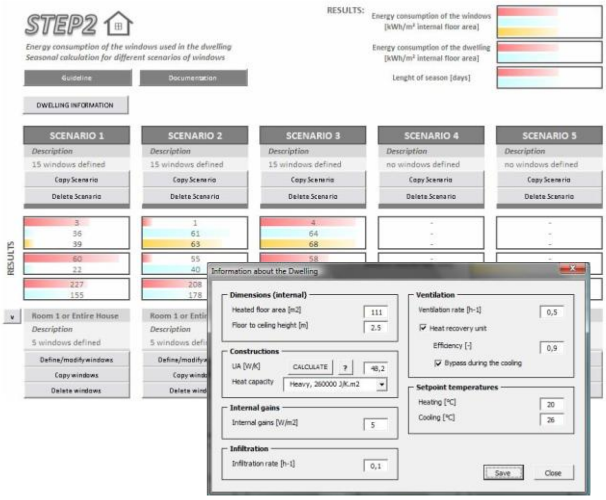

Fig. 3: Graphical User Interface of Step 2.

The energy consumption of the windows integrated in the dwelling is then calculated for each scenario for both the heating and cooling season, based on seasonal average values of weather data. The specific heating season and cooling season for the building is automatically calculated and used.

Step 3: Hourly calculation of energy consumption and thermal comfort in room

In step 3, rooms of the dwelling defined in step 2 need to be selected to define a thermal zone on which the hourly calculation will be performed. As a basis for the hourly calculation, the "simple hourly method" described in the Standard ISO 13790 has been used. In the most recent version of the program; the hourly calculation has been further developed, allowing the calculation of multiple rooms, taking into account the electricity needed for lighting and using an intelligent control for the building systems to maintain a comfortable indoor environment using no or very little energy.

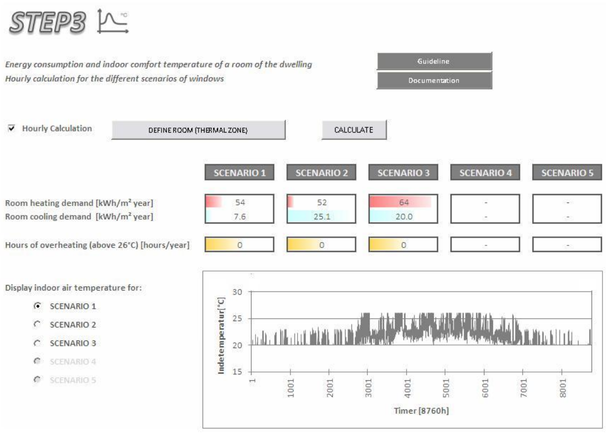

Fig. 4: Graphical User Interface of Step 3.

As a result from the hourly calculations in this step, the energy for heating and cooling as well as the number of hours with overheating are calculated for one year on an hourly basis, see Fig.4.

Step 4: Economical evaluation

Step 4 consists of an economic evaluation of the scenarios of windows previously defined in step 2. The evaluation is based on the calculation of the cost of conserved energy when using the selected windows solutions in comparison to a reference solution.

Conclusion

Based on the overview of the analyses made during the four steps, the user is from the calculations able to evaluate and compare the energy performance of different individual windows in a dwelling consisting of several rooms and can select the window solutions with the optimal performance in the actual dwelling.

Making use of a method to calculate the solar radiation on windows with arbitrary orientation and slope, weather data, an estimation of the energy use for electrical lighting and an intelligent control of the building systems, WinDesign is still a very user-friendly program with a fast calculation time that can be used early in the design process. This in contrast with more advanced programs that are often not used until much later in the design process.

However, some extensions could be added to the last version of the program. It is for example not yet possible to take into account efficiencies for the heating and cooling systems. Other extensions to the program can be made to allow the investigation of different scenarios for other building components but windows. For renovation of buildings, it might be useful to investigate the effect of different insulation thicknesses in the wall. A menu to easily change the UA value of the dwelling could then be added.

The last version of the program, WinDesign 2.0, is accessible at DTU Byg's Internet portal: http://www.vinduesvidensystem.dk/.

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Air distribution in a classroom with diffuse ceiling ventilation

Ph.d.-research project: Christian Anker Hviid

Introduction

The relationship between fresh air, temperature and productivity has long been established and modern indoor climate requirements demands large amounts of fresh air. But fresh air must be supplied to the comfort zone without draught. Principles of mixing or displacement are commonly used but are restricted in terms of inlet temperature (cooling effect) supplied flow and diffuser placement.

Diffuse ceiling inlets shows a promising compromise for supplying large amounts of fresh air to the room at a low temperature and virtually without the risk of draught (Jakubowska 2007, Jacobs et al. 2008).

The principle is illustrated on Figure 1 where fresh air is supplied above a suspended porous ceiling. Thus the ceiling acts both as air diffuser and acoustic damper.

The results presented here are generated through measured properties of the porous ceiling in a test room and applying the measured ceiling as diffuse ventilation in CFD-simulations of a classroom.

Measurements

Measurements are carried out in a test class room with tables, heat sources and ventilation inlet as illustrated on Figure 1. The material of the suspended ceiling is aluminium plates 0.6 x 0.6 m with punched holes of Ø 2.5 mm. The open area ratio is 0.162. On the upper surface of the plate is an acoustic textile of 0.22 mm thickness glued on. The textile is penetrable by air but causes the main pressure loss.

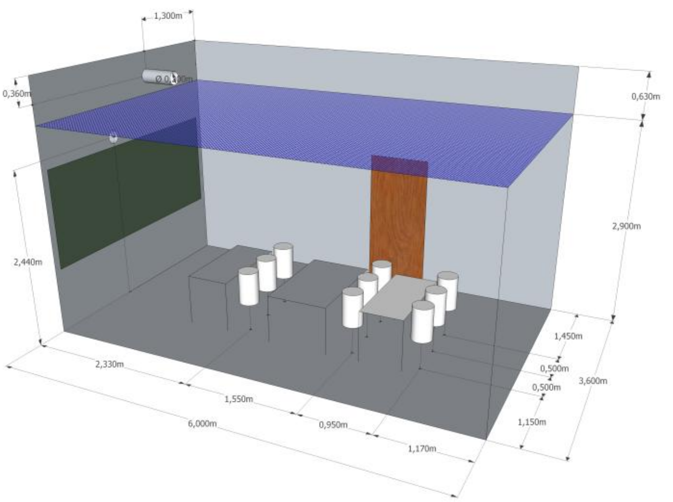


Figure 1. Test class room with blue color illustrating porous ceiling.

Data for pressure loss, global and local air change efficiency, inlet temperatures and local air velocities were collected.

Results

Results are shown in Table 1 and Figure 2 – Figure 4.

Table 1. Measurement data from test room. Air change efficiency is a measure of how effective the ventilation system replaces air present in the room with fresh air; full mixing 50%, piston flow 100%.

	Air change (h^{-1})		
	0.89	1.50	1.92
Inlet temperature (°C)	14.6	14.7	13.8
Ceiling temperature (°C)	21.1	20.2	20.7
Room average temp. (°C)	23	23	23
Air change efficiency (%)	52.8	49.6	48.5

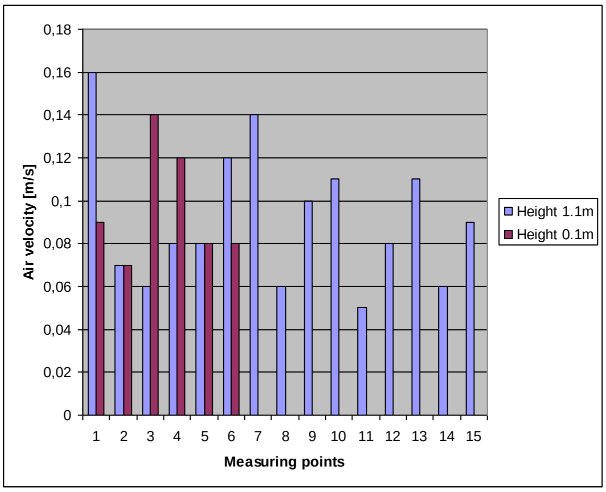


Figure 2. Local air velocities in test room.

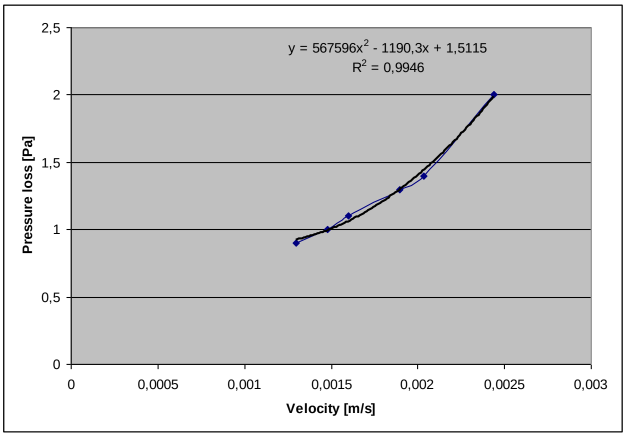


Figure 3. Pressure – velocity relation for porous ceiling.

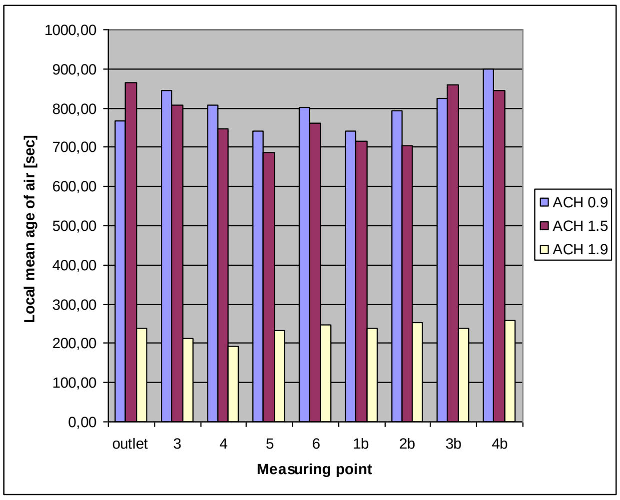


Figure 4. Local mean age of air at different measuring points in the test room.

CFD-simulations of classroom

The measurements were only carried out for a small scale test room. To investigate the performance in full scale rooms with high heat load, the CFD-program Fluent was used to simulate a class room. The ceiling is modelled as a porous jump where the jump-model below is fitted to the measured (q,ΔP)-relation from Figure 3.

$$\Delta p = -\left(\frac{\mu}{\alpha}\upsilon + C_2 \frac{1}{2}\rho\upsilon^2\right)\Delta m$$

The parameters are: μ dynamic viscosity 1.79·10-5, α permeability of the medium, C2 pressure-jump coefficient, v velocity normal to the porous face and Δm thickness of the medium. With the values in

Table 2 (indoor climate class III, ACH 2.4), pressure drop Δp = 0.6 Pa. The inlet air is cooled to 4 °C below average room temperature.

Discussion

The measurements show almost perfect mixing in the test room with no risk of draught in the comfort zone, only one point shows an air velocity of more than 0.15 m/s. The air change efficiency in Table 1 proves full mixing and with no stagnant zones as the mean age of air in Figure 4 illustrates.

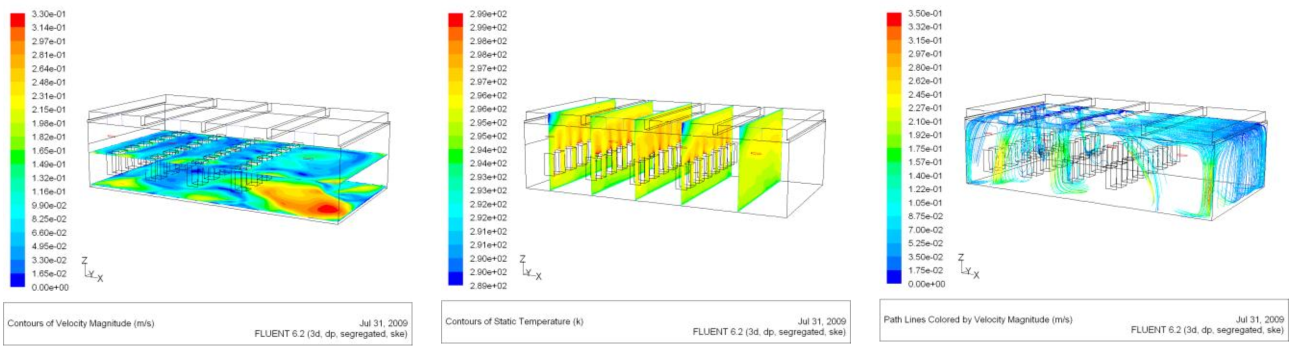
The CFD simulation shows pleasant temperatures and air velocities in the comfort zone except for a narrow down draft in connection with the inlets. In one corner the down draft reaches 0.33 m/s. Temperature distribution is even.

The main advantage of the diffuse ceiling inlet is the small pressure loss with good distribution and hence adaptability to a natural/passive/hybrid ventilation system where low pressure loss is essential.

Further investigations should be conducted on the activation of the concrete deck in pre-cooling /-heating the inlet air.

Table 2. CFD input.

Volume flow rate (m^3/s)	Inlet velocity (m/s)	Inlet air temp. (°C)	Wall temp. (°C)	Ceiling temp. (°C)	Window wall temp. (°C)	Radiation	No of persons	Heat sources (W/person)	Permeability α (m^2)	Medium thickness (m)	Jump-coef. C_2 (1/m)
0.15	0.0939xx	16	20	17	18	Not incl.	24	125	3.95E-10	0.0007	38.3



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Demand controlled ventilation in single family houses

Associate Professor Toke Rammer Nielsen

The project is concerned with strategies for demand controlled ventilation in single family houses with balanced mechanical ventilation. Two strategies are investigated: 1) a simple strategy based only on sensors for CO_2 and humidity in the air handling unit that control the speed of the fan 2) an advanced strategy based on measurements of CO_2 and humidity in the individual rooms with individual flow control to each room. At the moment results for the first strategy are available and the second strategy is currently being tested. The strategies are tested in an existing single family house occupied by two adults and two children. The floor area of the house is 140 m². Initially CO_2-concentration, relative humidity and temperature were measured with the existing ventilation system running at a constant air change rate. The occupants often found it necessary to open windows to avoid high temperature and a sensation of poor air quality. This was mainly the case for the parent's bedroom where often also a child sleeps. Figure 1 shows the CO_2-concentration in the rooms during one week in February. February 19. the mechanical ventilation is shut off to see the consequences. It is seen that mainly in the bedrooms the CO_2-concentration is above 1000 ppm which indicates a poor indoor air quality. During the day time the house is empty and the CO_2-concentration drops with in a few hours to appr. 500 ppm. This could justify reducing the ventilation rate during the daytime.

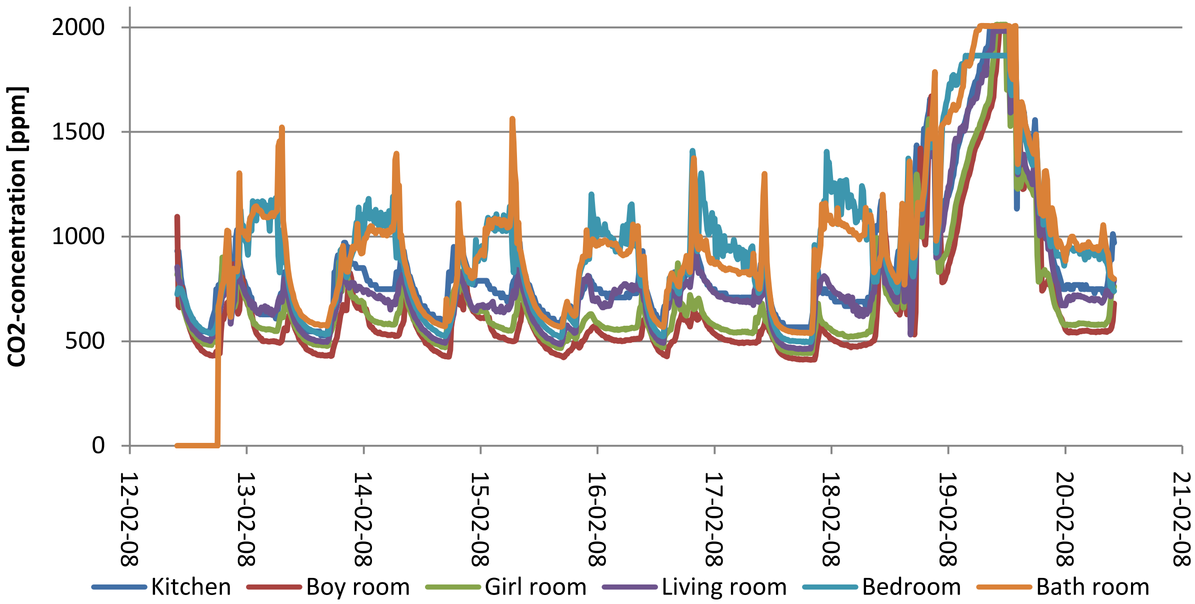

Figure 1. CO_2-concentration in the house with the existing ventilation system. February 19. the mechanical ventilation is shut off.

Simple demand control

In the simple demand controlled system the air flow can vary between a high and a low setting. The high setting gives an air exchange of 0.35 l/(s m²) (the current requirement for constant ventilation rate in the Danish building regulations) and the low setting gives an air exchange of 0.1 l/(s m²) (based on requirement for empty office buildings from EN 15251). With the simple system regulation on room level is not possible.

The main idea is that the ventilation should run on the low setting when no people are in the building and the humidity level in the building is low. The difference in CO_2-concentration between the supply air and the exhaust air is used for occupancy control and the difference in absolute humidity between the exhaust air and supply air is used for humidity control. Several settings for accepted difference in absolute humidity and CO_2-concentration have been tested. Results are presented for a period where a difference in absolute humidity of 2 g/kg and CO_2-concentration of 150 ppm is used to switch between the high and low air flows. With this setting the ventilation was running 63% of the time with high flow and 37% of the time with low flow. Figure 2 shows the measured differences in absolute humidity and CO_2-concentration in the air handling unit and the speed of the fan. Figure 3 shows the CO_2-concentration in the living rooms during the same period. Comparing figures 1 and 3 show that the indoor air quality expressed as the CO_2-concentration does not change significantly between the system running at a constant ventilation rate during the day and the system running with a lower ventilation rate when the house in unoccupied. This indicates that it is possible to reduce the air flow (and the electricity consumption) when the house is not in use and still deliver the same air quality.

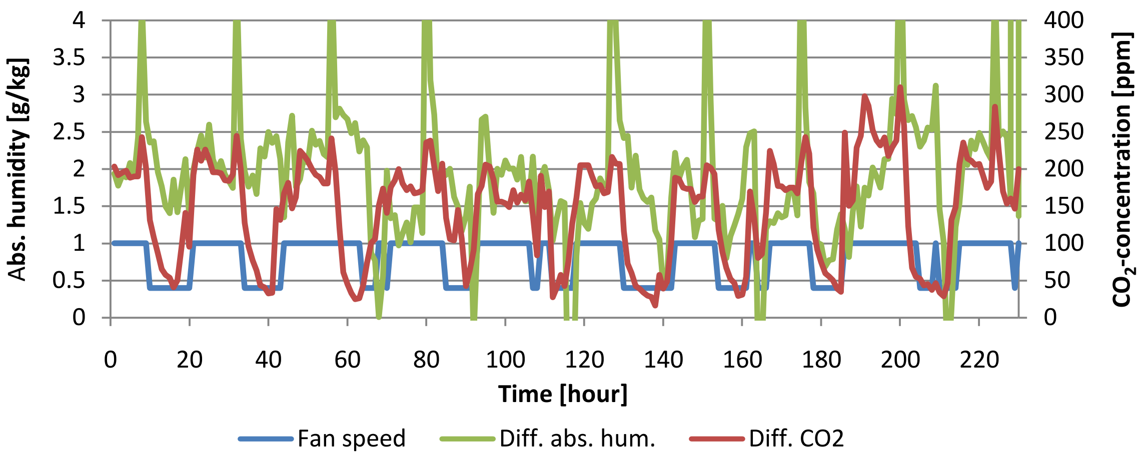

Figure 2. Results for difference in absolute humidity and CO_2-concentration measured in the air handling unit and the speed of the fan with the simple demand control in operation.

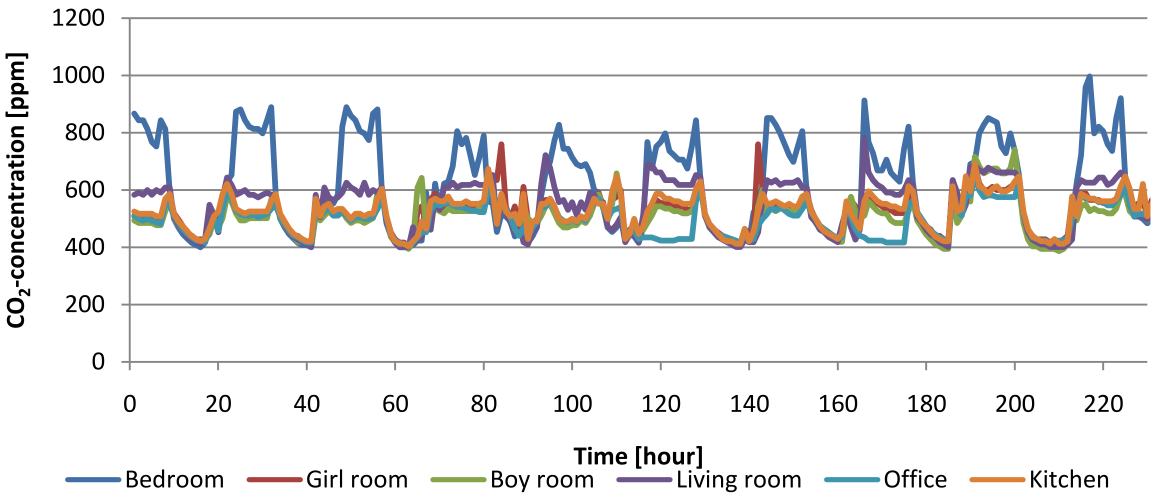

Figure 3. CO_2-concentration in the living rooms with the simple demand control in operation.

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Energy saving retrofitting of buildings to low-energy level

PhD project: Martin Morelli

Summary

The PhD project deals with energy-renovation of multi-storey buildings to achieve an energy consumption corresponding to new erected low-energy buildings. The main objective is to determine the time and the extent of renovation with focus on new long-lasting retrofitting solutions.

Introduction

According to the Kyoto Protocol the Greenhouse Gasses (GHG) in Europe are to be reduced with 8% in 2012 compared with the level in 1990. Denmark has decided to reduce the GHG with 21% within this period.
In Denmark and the rest of Europe the total building sector uses about 40% of the total primary energy consumption (Tommerup & Svendsen, 2005). New buildings represent about 1% of the total building mass; hence, the potential of saving energy is in existing buildings mass.
Until now Denmark has mainly focused on new erected low-energy houses. As a comparison to Denmark, Germany, Austria and Switzerland have for several years also focused on retrofitting the existing buildings to e.g. Passive House standard.
The Danish government has a long term goal which is to be 100% independent of fossil fuels. There is a potential for profitable space heating savings over the next 45 years (up to 2050). The saving potential of energy used for space heating is assessed to be around 80% (Tommerup et al., 2004).

Fig. 1: Multi-storey building in masonry, Danmarksgade, Aalborg (arks.dk).

Unfortunately, the financially budget often determines the level of renovation, which probably is due to that the costs for renovation are mixed with the costs to save energy on the long term. It is therefore important to distinguish renovation cost from saving of energy cost (Martinaitis, Kazakevicius & Vitkauskas, 2007).
It is of great importance that the market value of the retrofitted buildings increases more than the cost for energy-renovation (Zavadskas, Raslanas & Kaklauskas, 2008).
Denmark has a great tradition of building with brick walls, which leads to many facades worthy of preservation. The many multi-storey buildings next to each other results in challenges with outside insulation due to displacement in the facades and involvement of the pavement see figure 1.
Creation of retrofitting solutions, the total costs of renovation and preservation of the Danish architecture are examples on important issues regarding energy-renovation. Until now there has been no study of this. This PhD project will lead to a better understanding of energy-renovation on building components and whole buildings, which will be beneficial for all of us.

Example of facade insulation

Buildings from before 1920 are built up with masonry walls and wooden floor beams. These buildings have a great energy saving potential in the building envelope. Figure 2 shows how the beams are supported on the facade lying on the protruding bricks.

Fig. 2: Support of beams in the wall (danskbyggeskik.dk).

These buildings are often designed with facades worthy of preservation. External insulation is thereby impossible. Internal insulation changes the temperature of the inner part of the wall. This may have a negative effect on the moisture content of the wall due to the absorption of the driving rain. Furthermore the temperature profile of the wall after internal insulation leads to drying to the outside. As a result, water may accumulate in the masonry and at the beam ends embedded in the masonry with the risk of rot.

In this case it is very important to take the driving rain and sun into account. The combination of internal insulation and a perfectly tight vapour barrier may result in having moisture from the outside instead of from the inside as usually. Figure 3 shows two ways of insulate masonry - inside and outside. Figure 3 also shows the parameters that should be taken into account when analysing the solutions.

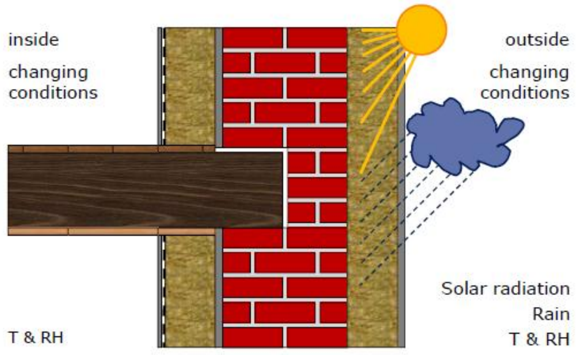

Fig 3: Masonry with wooden floor beam. Possible ways of insulating masonry and parameters influence the retrofit solution.

Objectives and Methodology

The hypothesis of the project is that the development of new energy saving retrofitting buildings can contribute positive to a sustainable development without fossil fuel.

The object of the project is to develop a method to secure new long-lasting renovation solutions of the building envelope and services to extensive building renovation. Future building renovation needs analysed solutions regarding service lifetime, environmental impact and saving of energy. Further it is expected to provide a method to evaluate a whole building in proportions to renovation in an economically optimized way.

Long-lasting retrofit solutions

First part of this PhD project is working with different retrofit solutions of the building envelope and installations. The new solutions need to be long-lastning retrofit solutions.

The solutions for energy-renovation will be developed on basis of known methods for product development e.g. Quality Function Deployment (QFD). Using QFD the user demands will be transformed into design quality and acheving the design quality into component parts. The solutions will be testet thoroughly in analyses, simulations programs and case studies. Further the service liftetime will be determined from research and knowledge based methods e.g. FMEA and ISO standard (Lacasse & Sjöström, 2005). No research regarding the use of FMEA with building components has been found in literature. Further the construction costs, energy savings, service lifetime, environmental impact and indoor environment are assessed.

Whole building renovation

Second part of this PhD project is to develop a method of an overall analysis of the need for energy-renovation. The primary area is to assess the building for needs of renovation and energy savings to achieve low-energy level. The low-energy level may be reached by designing the overall economically optimal solution of energy-renovation. Operation and maintenance costs will be included in the overall economic optimal solution. It is intended to compare the optimal energy-renovation solution with a new low-energy building regarding energy consumption, economic and environmental impact.

The theories are planned to be verified in practice on minimum two case studies. The multi-storey buildings will be energy-renovated with regards to the building envelope and/or the building services. The solutions are evaluated in proportions of the energy consumptions and overall economy.

Anticipated results

This PhD project will lead to a better understanding of energy-renovation, which may results in long term savings for the Danish society. Furthermore a better understanding of energy-renovation can contributes to meet the demand in the Kyoto Protocol and pursue the Danish aim of becoming independent of fossil fuels

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Design of energy renovation of typical buildings – elaboration of collection of examples

EUDP project (2008-2009) in cooperation between DTU, SBi-AAU, AAU, Cowi and TI.

Summery

The energy saving potential by energy renovating the existing building stock in Denmark is very large but the implementation of energy savings is only carried out to a small extend. In order to encourage the completion of energy renovations in buildings there is a need for improving the foundation for evaluation and selection of the optimised solutions. The objective of the project is to develop a method for design of extensive energy renovations that will encourage the completion of energy savings in existing buildings to reach "low energy class 1" level. The development of the method will be based on detailed analysis on the effect of the partial energy saving measures carried out in buildings. The analyses will be made for typical building types and the results will make up an example collection of buildings that represent the total building stock in Denmark. The developed method including examples will constitute a strong and reliable foundation for implementation of the best energy saving solutions in different building types. If done correctly it will also be possible to improve the indoor environment by energy renovations. This important additional benefit will also be evaluated in the form of improved comfort, less health risk and increased productivity.

Background

The energy saving potential by energy renovation of existing buildings in Denmark is very large since 40 % of the total energy consumption is used in buildings and most of the building stock is in poor condition regarding energy performance. Implementation of the potential energy renovation throughout the building stock in Denmark will to a great extend contribute to reach the goals for energy supply security and CO_2-reductions. However, for different reasons, only a few of the potential energy saving solutions are accomplished. One of the barriers for conducting energy saving retrofit measures might be lack of knowledge on how the renovations should be handled the right way and which specific measures that will give the largest savings in the actual building. Therefore there are needs for guidelines describing the best energy renovation measures for different types of buildings.

There are large differences on how different building types can be energy renovated to obtain the highest energy savings. It depends on the energy performance conditions of the building. Type, age and application of the building have influence on which energy renovation measures that are the most efficient and cost effective. In order to obtain the best energy renovation solutions for specific buildings there is a need for analyzing different energy-efficiency measures in retrofits for typical building types. The effort for implementation of energy savings in retrofitting must be systematized in order to exploit knowledge from different projects and share the good experiences among architects, consultants and building clients etc.

To convince a building owner to invest in an energy renovation it is important also to show the benefits regarding improved indoor environment (comfort-health-productivity) that will be obtained.

Earlier studies

Earlier there have been made some similar projects as, "Energirigtig renovering af store bygninger – udvikling og demonstration med hovedvægt på installationer og forsyning" (EFP project 2006) and " Renovering 2010 – Initiativ til udvikling af bygningsrenovering i Danmark" (www.renovering2010.dk financed by GI and Realdania).

Objectives and Methodology

The objective of the project is to establish a method for design of extensive energy renovation of buildings to low energy class 1 based on an example collection of energy renovation of typical building types. The development of the method and the examples will be based on detailed analyses of the effect of different energy saving measures on a component level when implemented in typical building types. The work shall include the development of standardised guidance/directions on how to document and report the results and gained experiences in other research or demonstration projects so that future knowledge on the topic will be collected in a useful way. The results from the analysis will form a collection of examples of the best energy renovation solutions accomplished in building scenarios that represent the total building stock in Denmark. The developed method including examples will constitute a strong and reliable foundation for implementation of the best energy saving solutions in different building types. The developed standard documentation system and the example collection must be accessible from the internet so that operators in the building renovation market can upload their results and experiences and take advantage of the knowledge already existing.

Project plan

The project encompasses 3 parallel activities:

1. Thorough analyses of the many possible energy saving retrofit measures on component level including energy saving potentials for upgrading to energy improved components and price calculation of the additional costs of construction and operating costs compared to conventional renovation. The analyses will focus on retrofitting measures regarding walls, roofs, slab on ground, foundation, air tightness of building envelope, windows, solar shadings, heating

and cooling systems, ventilation, lighting, solar energy, building maintenance service and operation.

2. Analyses of the different energy renovation measures used on whole buildings – carried out on typical buildings. This activity include: 1) Selection of the buildings to be analyzed, i.e. the most typical buildings in Denmark based on age, application and types, 2) Calculations of the energy saving potentials for implementation of complete extensive energy improvements to the level of "low energy class 1", 3) Calculation of the costs of construction etc. involved. 4) Evaluate and quantify the potential indoor climate effect (comfort-health and productivity) of the energy renovation. This evaluation will include an estimation of potential cost savings due to better health (less sick leaves etc), better learning effect (educational facilities) and increased productivity

3. Development of a standard documentation system containing all necessary information concerning energy renovations. This system and the example collection of state-of-the art energy renovation solutions for typical buildings will be part of the homepage for the LavEByg network – Innovation network for integrated low energy solutions in buildings (see www.lavebyg.dk).

Anticipated results

The results from the project will form the basis of an example collection of energy renovation solutions for building categories representing the whole building stock in Denmark. The method for design and documentation of energy renovations is supposed to be used in future related projects within the LavEByg network. In this way the results and experiences from related project concerning renovation will be registered and added to the collection which will benefit other energy renovation projects.

The project will most likely document that comprehensive energy renovations in most cases are cost effective although the initial costs of the constructions seems high compared to the energy savings. By including the lifetime of the application, the indoor environmental improvements and the fact that only the extra cost for implementing energy savings should be taken into account in connection with need of renovation, an extensive energy renovation is often economical lucrative.

References

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Low-energy buildings and heat supply systems based on renewable energy

Ph.D project: Alessandro Dalla Rosa

Background

Energy savings and the use of renewable energies is a priority for the world energy policy. Energy consumption in buildings is one of the main target areas, since by 40% of the energy consumption in developed countries takes place in buildings. A matter that is important to investigate in next future is the application of low temperature district heating systems (DH) for low-energy buildings. DH consists of centralized heat production facilities with associated distribution networks. The aim is meeting the demand for space heating and hot tap water. Different strategic resources have been identified as suitable for district heating (DH): combined heat and power (CHP), waste incineration, industrial surplus heat. At present time it is a well-developed and competitive technology when the heat supply is delivered to areas with high heat densities; nevertheless the percentage of fossil fuels (coal, oil, gas) involved is still too high in comparison to the energy policy targets. Preliminary studies [1,2] illustrate that DH is applicable in a cost-effective way also to low energy buildings, despite their very low heat demand, thanks to the development of a network with low heat losses. As a consequence of the lower spacing heating demand the hot water heating loads will increase their relative importance [3]. Nevetheless, sometimes, due to low heat demand in new buildings, the profitability in supplying DH is decreased and electricity-based heating systems may therefore be chosen as suitable solution [4]. DH from cogeneration of electricity and power is often more resource-efficient than other heating system, regarding annual primary energy use, annual CO_2 emission, annual cost of heating [5]. DH networks can enhance technical co-operations between energy-intensive industries and municipal energy companies, for instance by utilizing industrial waste heat as the primary source in DH pipelines or by commonly owning plants that produce both process steam for factories and hot water for DH [6]. Due to the large amount of different technical options, there is therefore the need of research on which are the parameters that might help to choose the economically and environmentally best plant for a given situation.

Aim and hypothesis of the project

The aim of the project is to investigate possible new or improved technologies for developing an optimal combined solution for the heat supply to low energy buildings based on non-fossil fuels. The heat supply systems can be low temperature DH with multiple heat sources and heat storages. The heat supply system can also be electrical heat pumps with electricity from wind mills or other renewable electricity producing systems combined with solar heating systems on the building. Both systems are improved for use in low energy buildings and cost of delivering renewable energy are compared to cost of saving energy in low energy buildings. The hypothesis is that it is possible to develop new or improved economical optimized combined solutions for energy supply of low energy buildings that do not need energy from fossil fuels. Another fundamental hypothesis of the project is that these solutions will become more and more competitive in the future, due to increasing costs of fossil fuels, introduction of new energy legislation and a deeper environmental awareness [7]. Moreover the substantial amounts of waste and surplus heat from CHP in combination with the developing prices of coal, oil and gas will make feasible to expand DH systems and other innovative heating plants into areas so far supplied by fossil resources. Theoretical and practical studies will have the objective to show that DH with renewable energy (geothermal energy, large scale solar heating) or with use of surplus heat from industrial processes, waste incineration plants and biomass CHP plants has large environmental and socio-economical benefits.

Content of the project

The project starts with an overview of which are the concrete possibilities to decrease the total demand of heat in different typologies of buildings, considering low-energy houses and offices, renovated or existing buildings. Efforts will be made in order to evaluate the relation between energy savings in heating of buildings versus their costs. It is important to analyze the economical and environmental implications of improving the performance of buildings about heat demand and to understand the actual weight of heat requirement on the total energy demand (mainly electricity and heat). Creating correlations between heat consumption, energy savings and economical costs will be the basis to assess the best options for future development of improved heating systems. After that several other aspects have to be analyzed. With regard to DH network system, surveys are needed on pipe types, insulation of ducts, the choice of the proper consumer unit (heat exchanger unit, domestic hot-water storage unit, new DH storage units) and the space heating system. New district heating systems must focus to exploit local energy sources. Surveys are necessary to find out new ways of power storage and load management. Future buildings with high performance envelope (high levels of insulation, high-quality windows, minimal uncontrolled leakage and heat recovery from ventilation exhaust) will lead to reduced space-heating load and therefore to lower required distribution temperature for heating. Other interesting topics to investigate are the possibilities to apply DH in areas with low heat demand density and to develop the best alternatives in the cases where the system is not technically and/or economically feasible. The objective is to increase the use of DH instead of electricity in households, and to encourage the use of low-energy systems. Some recent studies [8] state that, expressed in terms of heat density, areas with a heat density as low as 10 kWh/m^2,yr can be economically served by DH. District heating requires careful planning and design in order to achieve good economy for low heat demand density. Theoretical and experimental investigations have to be carried out in order to achieve the goal of an effective design. This regards low pressure and low temperature networks, reduced pipe dimension, proper insulation and attention to design the proper consumer unit. Solar heating plants and heat pumps are well-known technology, but their combination and their interaction with DH need extra research efforts. Solar thermal is a mature technology with an annual average growth of almost 20%, but the major challenge is its connection to DH network. DH has an important role in utilizing thermal solar heating in large scale, since this kind of plants allow lower investment costs and higher efficiency than small-scale solar heating systems, which might be a good solution instead of electric heating or individual boilers for standing alone buildings. Concerning heat pumps, their integration to the DH is at research phase [9]; integration in electric systems with large shares of wind power and CHP is an interesting application of heat pumps as it opens the opportunity for additional utilization of fluctuating electricity production. This may be used for driving heat pumps and can thus make it possible to have renewable energy in the DH system. The research is aimed at an improvement of system coefficient of performance (COP). At present time the COP that can be obtained is not completely satisfactory, due to the requirement of a large temperature difference between low temperature heat source and the relatively high temperature forward in the DH network. The introduction of low temperature DH networks might be a good solution also to enhance the performance of this kind of plants. Absorption heat pumps, driven by waste heat, are interesting applications as well.

Achievements of the project

An efficient low-temperature network will increase the performance of the DH and will allow to use heat sources more efficiently, such as solar heating, geothermal energy, low temperature surplus heat. During this PhD project the main objective will be the study of solutions to adapt and to enhance heating technologies that involve renewable energy use to the new scenarios about improved technologies, low-energy buildings and future energy policy. This will be done in order to design cost-effective systems and with particular attention to environmental consequences, energy saving improvement, development of renewable energies. Surveys will be carried out to investigate the best solutions both for high-energy density areas and low-density areas. Moreover the project will focus on different qualities of buildings, including low-energy houses and retrofit buildings. Suggestions will be prepared in order to create the foundations of CO_2-free heating systems.

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Simulation of thermal indoor climate in buildings

Associate Professor Jørgen Erik Christensen

Introduction

Simulation of energy consumption in buildings on hourly basis is closely connected to the thermal indoor climate. However in many programs the model for calculating the indoor climate has traditionally been based on a relatively simple model for the operative temperature independently of the location of the person in the room. In practice the location of the person has a significant influence in buildings with greater glass surfaces.

The surface temperature can easily be measured or calculated. However, the angular factor between a sedentary/standing person and a rectangle on the wall, floor or ceiling is far more complicated to calculate seeing that the Human Projected Area Factor is involved in this calculation. Since it is complicated to measure the Human Projected Area Factor, results from resent research are used as a background to set up a simpler model to be used in simulation programs on hourly basis for energy consumption and indoor climate. The model can be used for simulation of the operative temperature dependently of the location of the person in the room. The model described in this paper can easily be implemented in simulation programs for energy consumption and indoor climate thus making a picture of different locations in the room throughout the year.

Mean Radiant Temperature and Operative Temperature

The idea behind the operative temperature is to simplify complicated thermal conditions, where the air temperature, the radiant temperature and the air movement are involved:

$$t_o = A \cdot t_a + (1 - A) \cdot \overline{t_r}$$

where t_o = the operative temperature [ºC], t_a = the air temperature [ºC], t_r = the mean radiant temperature [ºC], A = a factor accordance to the relative air velocity.

The mean radiant temperature $\bar{t}_{r,P}$ is defined as the uniform temperature of the surrounding surfaces, which will result in the same heat loss by radiation from a person as the actual conditions of the surroundings. The mean radiant temperature between a person and the surrounding surfaces can be calculated from:

$$\bar{t}_{r,P} = F_{P-1} \cdot t_1 + F_{P-2} \cdot t_2 + \dots\dots + F_{P-n} \cdot t_n$$

where $t_{r,P}$ = the mean radiant temperature for a person [ºC], t_i = the temperature of surface i [ºC], F_{P-i} = the angular factor between a person and surface i [–].

In simulation programs on hourly basis for energy consumption and indoor climate in buildings, the surface temperatures will usually easily be calculated. However, the angular factor between a sedentary /standing person and a rectangle on the wall, floor or ceiling is far more complicated to calculate. As a result of this most programs use an area average waited value in the calculation of the mean radiant temperature. The consequences of this are that the location of the person in the room has no influence on the result.

Example – Modern Apartment

The finishing and sale of a couple of very mentioned buildings in Denmark have set new standards for how much glass you can use in a house facade. The technical development of windows with low U-values has made it possible to build houses with windows from floor to ceiling. However now architects and engineers are facing the fact that as the window areas get bigger it is increasingly more difficult to create fine overall solutions concerning the thermal indoor climate, energy consumption, sunshade devises, airing from open windows, furnishing possibilities, shielding against people looking in, etc.

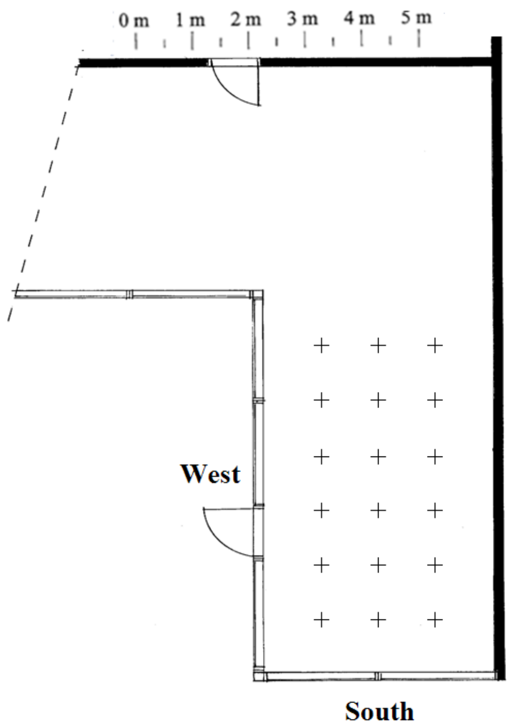

Fig. 1: Modern south/west facing apartment with windows from floor to ceiling.

The importance of calculating the mean radiant temperature according to the actual location in the room is shown for an example with a new apartment, where there are windows from floor to ceiling in two facades in the drawing room, figure 1. The apartment is heated with floor heating. The glazed south façade is 4 m wide and the glazed west façade 6 m long, which give an area of 30 m^2 exposed to big glass areas. The room height is 2.6 m.

The results of the calculations of the mean radiant temperature have been shown on figure 2 for 3 pairs of curves for the three different kinds of glass types. The mean radiant temperature as 1) a function of the distance from the south window and 2) an area weighted mean value independently of the distance – fixed value. As expected the mean radiant temperature is lower near both windows and increasing as the distance from the window is being increased. These results will give a more correct picture of the thermal condition in the room in which the location of the person has been taken into account. This is as opposed to what has been done in many programs for dynamic building thermal analysis, in which the mean radiant temperature has been calculated as an area weighted mean value independently of the location in the room – see the three curves with fixed values (horizontal curves).

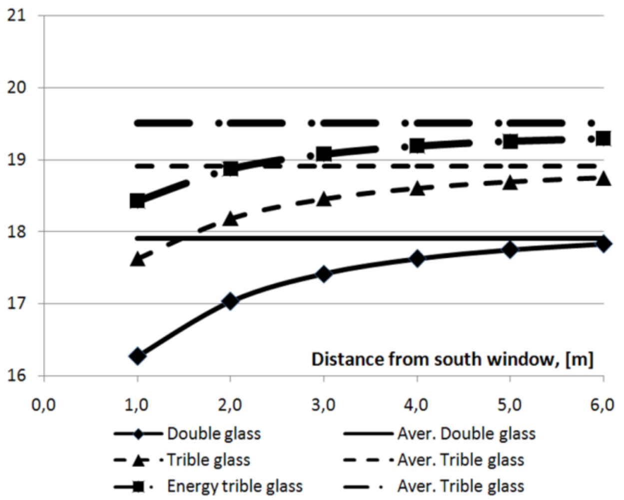

Fig. 2: The mean radiant temperature 1 m from the west window as a function of the distance from the south window.

In figure 3 the mean radiant temperature has been illustrated in a 3D landscaped form for a window with low energy triple glass. This figure illustrates how the temperature will vary around in the room compared to the mean radiant temperature as an area weighted mean value. This can be further developed to show the spatial distribution of comfort in the room in three levels: comfortable, just comfortable, and uncomfortable.

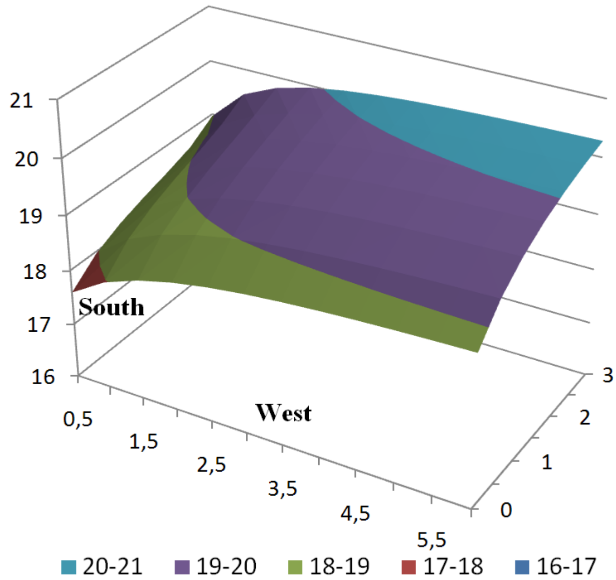

Fig. 3: The mean radiant temperature as a function of the distance from the west and south window for a low energy triple glass – see principle for grid in figure 1.

Implementation in BSim

It is a wish to implement a better model for the calculation of the mean radiant temperature in the computer program software package (BSim, 2005). The author of this paper has been a co-developer of the program in a former version *tsbi3* released in 1990. Later, the program has been incorporated as *tsbi5* into the computer program software package (BSim, 2005).

BSim is being used for research and commercial calculations by consulting engineers in the field of heating and air-conditioning. The program provides means for detailed, combined hygrothermal simulations of buildings and constructions. BSim can be used for analyzing indoor climate, energy consumption, passive solar energy, automatic control functions, etc. in connection with the planning and design of buildings, energy-conservation measures, renovation of buildings, and heating and air-conditioning systems. The program is the most used program in this field in Denmark.

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Innovationsnetværk for integrerede lavenergiløsninger på bygningsområdet – LavEByg

Støttes økonomisk af Forsknings- og Innovationsstyrelsen (2006-09): DTU Byg I samarbejde med Aalborg Universitet, Statens Byggeforskningsinstitut – Aalborg Universitet og Teknologisk Institut

Introduktion

LavEByg's drives af DTU Byg - Institut for Byggeri og Anlæg ved DTU - i samarbejde med Institut for Byggeri og anlæg ved Aalborg Universitet, Statens Byggeforskningsinstitut ved Aalborg Universitet og Teknologisk Institut (netværket kerneaktører). De øvrige deltagere i netværket er byggevareproducenter, rådgivende ingeniører, arkitekter, udførende, brancheorganisationer, andre faglige netværk samt offentlige myndigheder.

LavEByg's kerneaktører modtager samlet set et årligt tilskud på 2 mio. kr. til gennemførelse af netværksaktiviteter. Den tid netværkets private virksomheder bruger på netværksaktiviteter indgår som medfinansiering i projektet. Der har i 2006-07 været fokus på nye bygninger og i 2008-09 er fokus på renovering af eksisterende bygninger. Netværket har mulighed for at fortsætte udover 2009 for resterende midler samt en eventuel ny bevilling medio 2010.

Mission

LavEByg's mission er at styrke samarbejdet om forskning og udvikling af vidtgående energibesparelser og energieffektiviseringer i bygninger ved at bringe de forskellige aktører i form af videninstitutioner, byggevareproducenter, rådgivende ingeniører, arkitekter og udførende sammen i fælles forsknings- og udviklingsprojekter. Den overordnede mission er således at muliggøre en større anvendelse af forskningsbaseret viden i byggeerhvervet til løsning af de højteknologiske problemstillinger i forbindelse med udviklingen af integrerede lavenergiløsninger på bygningsområdet.

Vision

LavEByg's vision er at der gennem en styrket indsats og kontinuerlig udvikling af energirigtige og sunde løsninger til byggeriet, skabes grundlag for at alle nye bygninger og eksisterende bygninger der renoveres gennemgribende fra og med 2020 kan nøjes med et så lille energibehov, at det vil kunne komme fra vedvarende energisystemer. Kort sagt: Velfungerende bygninger med godt indeklima, men uden behov for energi fra fossile brændsler

Formål

LavEByg's vil søge at skabe det tekniske grundlag for at nedsætte hele bygningsmassens energiforbrug, som udgør 40 % af DK's samlede energiforbrug, til ca. 20 % af det nuværende i løbet af 40-50 år (se figur 1). Diverse undersøgelser viser at dette er teknisk muligt og forbundet med en god totaløkonomi, men det kræver en ny energiløsning, hvor der ikke anvendes fossile brændsler til bygningers energibehov, og som er baseret på vidtgående energibesparelser og energiforsyning med vedvarende energi.

LavEByg vil bidrage til det store potentiale for energibesparelser realiseres - både i forbindelse med nybyggeri til lavenerginiveau og ved energirenovering af eksisterende bygninger - ved primært at bidrage til, at der etableres relevante fælles forsknings-og udviklingsprojekter mellem vidensinstitutioner, private virksomheder samt relevante offentlige virksomheder og myndigheder.

Aktiviteter

Netværket gennemføre følgende former for aktiviteter:

- Strategiudvikling - F&U strategier for faglige indsatsområder
- Matchmaking - netværksmøder, udvikling af samarbejdsprojekter mv.
- Virksomhedsrettede ydelser - organisering af fælles F&U aktiviteter, bistå med initiering og udarbejdelse af F&U ansøgninger, arrangere årlig studietur og netværkskonference, udsendelse af nyhedsbreve mv.
- Formidling - af netværksresultater, vedligehold af hjemmeside mv.

Faglige fokusområder

- Hele bygningen
  - Boliger - enfamiliehuse og etageboliger
  - Kontor-, skole- og institutionsbyggeri mv.
- Klimaskærm
  - Isolerede klimaskærmskonstruktioner
  - Energivinduer
  - Glasfacader og –tage, inkl. solafskærmninger
- Installationer
  - Elektriske belysningsanlæg
  - Ventilation og luftbåren varme og køling
  - Vandbåret varme- og køleanlæg
- Energiforsyning
  - Lavenergifjernvarme til lavenergibyggeri
  - Bygningsintegreret solenergi (solvarme og solceller)

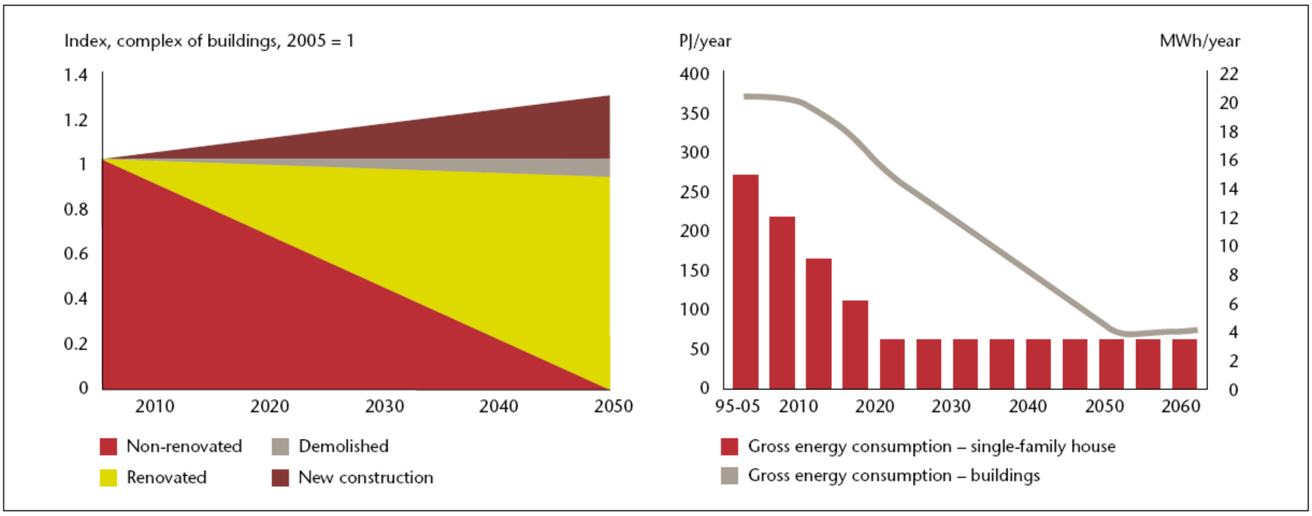
Resultater af netværkets arbejde

Der er blevet udarbejdet strategier for forsknings- og udviklingsmuligheder og –behov på området for integrerede lavenergiløsninger til nye og eksisterende bygninger. Der er udarbejdet ca. 60 projektansøgninger, hvoraf omkring 20 projekter har opnået støtte.

Netværkets kerneaktører og en række større private medlemsvirksomheder og Dansk Byggeri har søgt og fået 25 mio. kr. i støtte fra Det Strategiske Forskningsråd til "Strategisk forskningscenter for CO2 neutralt byggeri" for perioden 2009-15. Centeret skal skabe basis for en langsigtet bæredygtig udvikling i byggesektoren ved at udvikle CO2 neutrale bygningskoncepter via udvikling af integrerede, intelligente teknologier til byggeriet, der sikrer betydelige energibesparelser og optimal anvendelse af vedvarende energi. (web: www.zeb.aau.dk).

Netværket har desuden arbejdet for oprettelsen af et videncenter for energibesparelser i bygninger som startede op primo 2009. Centret samler og formidler viden om konkrete og praktiske muligheder for at reducere energiforbruget i bygninger til glæde for byggebranchens professionelle aktører. Denne viden omfatter bl.a. vejledning og uddannelse samt udvikling af værktøjer og effektive standard- og pakkeløsninger. (web: www.byggeriogenergi.dk).

Det skal også nævnes at netværket har bidraget til processen omkring oprettelse af et industri drevet Partnerskab for energivenligt byggeri (EnergiByggeri). EnergiByggeri består af de store faglige interesseorganisation, og ønsker at sætte skub i udviklingen ved at understøtte forsknings- og udviklingsprojekter inden for energirigtigt nybyggeri og energieffektiv bygningsrenovering. (web: www.energibyggeri.dk).



Figur 1: Scenarie for fremtidens energibesparelser i bygninger (til venstre), og bruttoenergiforbruget I bygningerne i samme periode (til højre)

Netværket samarbejder med andre netværk som f.eks. Industrinetvaerk.dk og VE-net, og har tilknyttede PhD'er i Integreret design af lavenergibygninger og energirenovering af bygninger til lavenerginiveau.

Netværket er også på EU niveau involveret i "Private-Public-Partnership on Energy-efficient Buildings" (PPP EeB), som er et samarbejde mellem den europæiske byggeindustri og EU kommissionen. EU afsætter over de næste 10 år ca. 1 mia. euro til udvikling af ny teknologi og innovative løsninger på bygningsenergiområdet forudsat at de europæiske byggevirksomheder medfinansierer med samme beløb.

Referencer

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5.2 Research activities in Solar Energy

The research on solar energy takes the solar energy technologies and their components as its starting point. To ensure a broad impact these technologies have to be integrated into the framework in which they are used. The group is therefore working on integration in energy systems, buildings and development plans.

Basically, the activities at system and component level should result in better price/performance ratios for solar heating systems of any kind, e.g. domestic hot water systems, combi systems and solar heating plants. This is achieved by increasing the knowledge of the thermal conditions and on the basis of that to form theories that can be used for thermal and economic optimization.

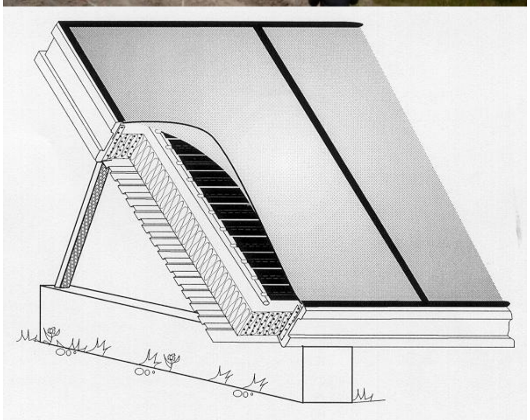
Development of solar collectors for solar heating plants

Research projects: *Simon Furbo and Jianhua Fan*

Introduction

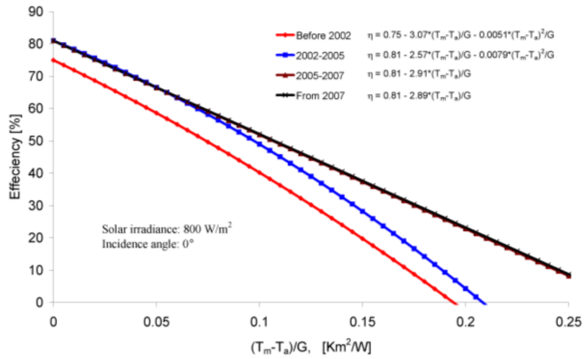
During the period 2002-2007 Arcon Solvarme A/S developed their so called HT solar collector for solar heating plants in cooperation with Department of Civil Engineering. The changes applied during the development:

Year	Changes
2002	Insulation material: Rockwool industribatts 40 instead of Isover glass wool Absorber: Absorptance still 0.95. Emittance reduced from 0.12 to 0.06 Glass: AFG Solatex instead of AFG Solite Antireflection treated glass: Glass surfaces etched by Sunarc Technology A/S
2005	Installation of Teflon foil improved to decrease thermal bridges
2007	Insulation material: Rockwool industribatts 80 instead of Rockwool industribatts 40 Improved edge insulation

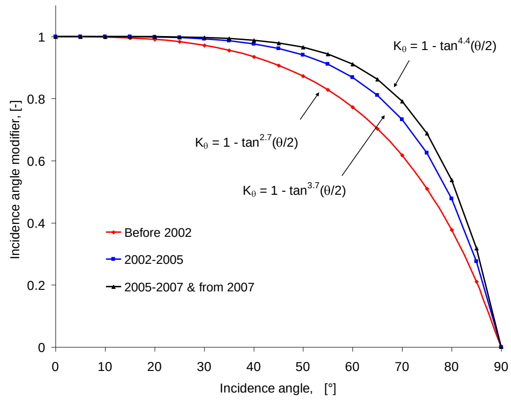


Left: Solar heating plant based on HT collector panels.
Right: Schematic sketch of HT collector.

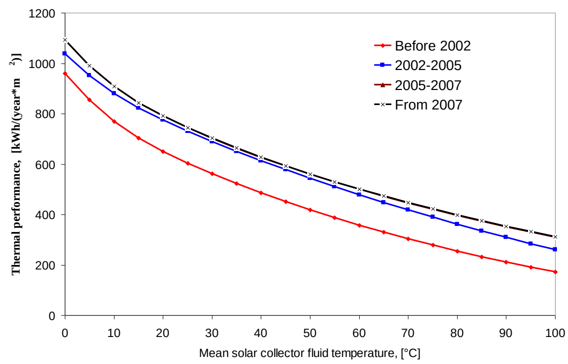
Improvements



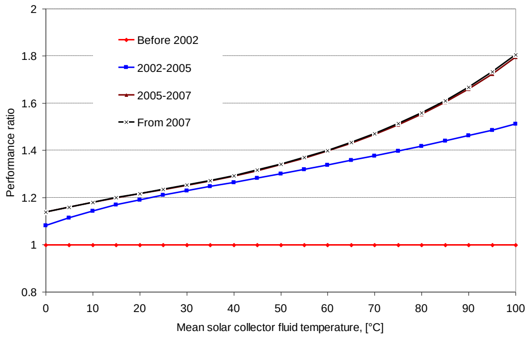
Efficiencies of solar differently designed solar collectors during the development phase.



Incidence angle modifiers of differently designed solar collectors during the development phase.



Yearly thermal performances of differently designed solar collectors during the development phase.



Relative thermal performances of differently designed solar collectors during the development phase.

Mean solar collector fluid temperature	**Improvement of thermal performance of solar collector from 2002 to 2007**
40°C	**29%**
60°C	**39%**
80°C	**55%**
100°C	**80%**

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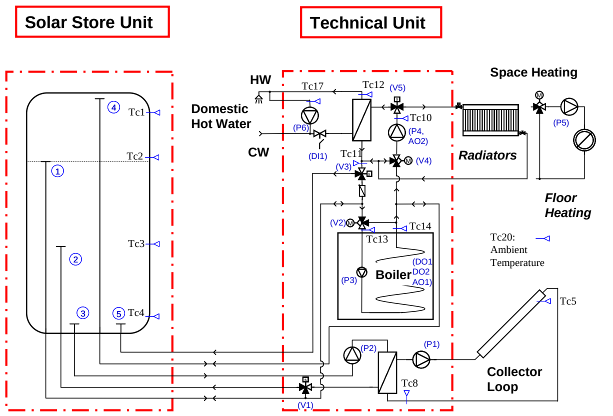
Energy savings in a one family house with a new developed solar heating/natural gas heating system

Research project: *Simon Furbo and Jianhua Fan*

Introduction

During the period 2003-2007 a technical unit and a heat storage unit for a solar heating/natural gas heating system was developed by METRO THERM A/S in cooperation with Department of Civil Engineering as a part of a Ph.D. project.



Schematic sketch of the solar/natural gas heating system.

The technical unit includes a modulating condensing natural gas boiler from Milton A/S, type Milton Smart Line HR24, with a nominal power for space heating of 5.7-23 kW and a nominal power for hot water preparation of 5.7-28.5 kW, a heat exchanger producing domestic hot water, and all equipment needed to operate the solar collectors, the natural gas boiler and the heating system. The heat storage unit includes a 360 l solar tank which can be charged by means of the solar collectors and the natural gas boiler. The tank insulation is partly PUR foam, partly vacuum panels.

Both the technical unit and the heat storage unit are built into 60 x 60 cm units by METRO THERM A/S. Due to this prefabrication, the installation of the system is easy and the risk of installation mistakes is reduced. The design of the units provides good operation conditions for the condensing natural gas boiler and for the solar collectors.

A one family house in Helsinge served as a demonstration house for a solar heating system based on the developed technical unit and the heat storage unit. A solar heating system was in 2006 installed in the house in Helsinge with 5 Velux solar collectors, type S08 with a total collector area of 6.75 m². The collector orientation is 15° towards east from south and the collector tilt is 45°. The collectors have a start efficiency of 0.79, a first order heat loss coefficient of 3.76 W/m²K, a second order heat loss coefficient of 0.0073 W/m²K² and an incidence angle modifier of $1-\tan^{3.9}(\theta/2)$, where θ is the incidence angle.

The photos below show the house before and after installation of the solar heating system.

Left: Demonstration house before installation of the solar heating system. Right: Non condensing natural gas boiler and separate hot water tank.

Left: Demonstration house with the solar heating system. Right: Solar tank and technical unit.

Measurements of the natural gas consumption and the energy demand of the house were carried out before and after installation of the solar heating system. The thermal performance of the solar heating system was measured as well.

Based on the measurements the energy savings of the solar heating system are for three years estimated to be in the range from 4400 kWh to 4900 kWh, corresponding to 650-730 kWh/m² solar collector per year. The energy savings are caused by the solar collectors, the new efficient natural gas boiler and a decreased domestic hot water consumption due to increased pressure drop of the domestic hot water installation of the solar heating system.

The energy savings will vary from year to year. In years with a high heat demand and a high solar radiation, especially in the spring, the energy savings will be high. In years with a low heat demand and a low solar radiation, especially in the spring, the energy savings will be low. The yearly heat production of the solar collectors is about 53% of the yearly energy savings. The measurements will be continued in the future.

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Energy savings for solar heating systems

Research project: Simon Furbo

Introduction

Only few investigations on energy savings for solar heating systems in practice have been carried out, [1]. This is remarkable since most solar heating systems are installed with the aim to save energy. The reason for the few investigations is that it is extremely difficult to measure/document the energy savings for solar heating systems in practice.

In order to determine the energy savings, seven energy quantities/efficiencies must be considered.

Before installation of the solar heating system:

- Utilization of energy for the energy system.
- Electricity consumption for the energy system.

After installation of the solar heating system:

- Net utilized solar energy of the solar heating system.
- Saved energy by turning off the auxiliary energy supply system during the summer.
- Utilization of energy for the auxiliary energy supply system.
- Electricity consumption for the auxiliary energy supply system.
- Electricity consumption for the solar heating system.

Further, to make the determination even more difficult, the above mentioned energy quantities and efficiencies and thereby also the energy savings are influenced by the heat demand and hot water consumption, which will vary from year to year due to weather variations, variations of user habits and due to changes of the hydraulics of the energy system.

A Swedish investigation of solar heating systems, based on questionnaires filled in by home owners, showed unexpectedly high energy savings for solar heating systems in practice. Also unexpectedly large variations of the energy savings were reported. Solar heating systems with collector areas between 4 m² and 25 m² were included in the investigations. The reported yearly energy savings ranged from 0 kWh per m² to 2750 kWh per m². The average collector area of the investigated systems was 11 m², and typical yearly energy savings ranged from 650 kWh per m² collector to 900 kWh per m².

A theoretical investigation showed that the energy savings of solar heating systems are strongly influenced by the efficiency of the energy system prior to installation of the solar heating systems [2]. Especially the efficiency during the summer period is of great importance.

The energy savings of typical Danish solar heating systems in one family houses will be evaluated in an ongoing research project carried out by Department of Civil Engineering in cooperation with Velux A/S, Batec A/S and Sonnenkraft Scandinavia A/S. The project is financed by the Danish Energy Authority. The investigations will be based on information from home owners of solar heating systems installed in 2008 and 2009 concerning the energy consumption in one family houses before and after installation of solar heating systems. The information will be analysed, and in this way typical energy savings of Danish solar heating systems will be found. It is expected that the energy savings of the solar heating systems are higher than normally anticipated and that the energy savings per m² for the Danish solar heating systems will be higher than the energy savings per m² of the Swedish solar heating systems due to the fact that the Danish systems are smaller than the Swedish systems.

Both solar domestic hot water systems and solar heating systems for combined domestic hot water supply and space heating from Velux A/S, Batec A/S and Sonnenkraft Scandinavia A/S are included in the investigations. The solar collector areas of the systems are varied in the interval from 2.2 m² to 12.5 m², the heat storage volumes are varied between 200 l and 800 l. Systems with flat plate solar collectors as well as systems with evacuated tubular solar collectors are included in the survey. Different auxiliary energy supply systems are used in the houses, such as oil fired burners, natural gas boilers, district heating supply, electrical heating systems and heat pump systems.

The project is scheduled to finish by the end of 2010.

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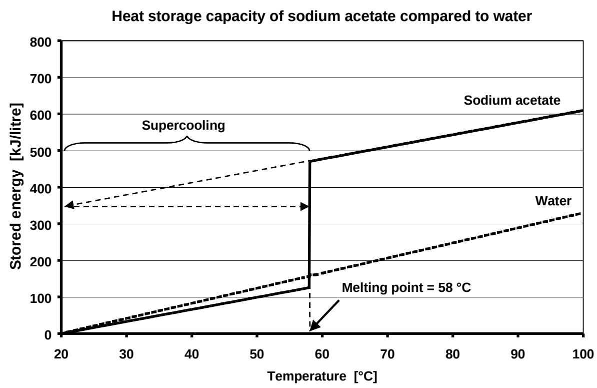
Seasonal PCM heat storage

Research project: Simon Furbo

Introduction

PCM (Phase Change Material) heat storages can be used instead of water heat storages in order to increase the heat storage capacity of the stores resulting in decreased store volumes. The most promising candidates among PCMs for heat storage materials for solar heating systems are inorganic salt hydrates with melting points in the temperature interval from 30°C to 60°C due to the relatively high heat storage capacity per volume. Further, some salt hydrates can in a stable way cool down as a liquid without solidification at the melting point or at temperatures below the melting point, that is: The salt hydrate is super cooled in a stable way. By making use of a stable super cooling it is possible to obtain a heat storage which in periods has no heat loss. The salt hydrate can be melted in sunny periods during summer. The salt hydrate can super cool down to the ambient temperature and the solidification can be activated in the winter when heat is needed. In this way the heat storage has no heat loss in the period where the salt hydrate temperature is equal to the ambient air temperature.

The process is illustrated in the figure for sodium acetate trihydrate, which has proved to super cool in a stable way. The melting point for sodium acetate is 58 °C.

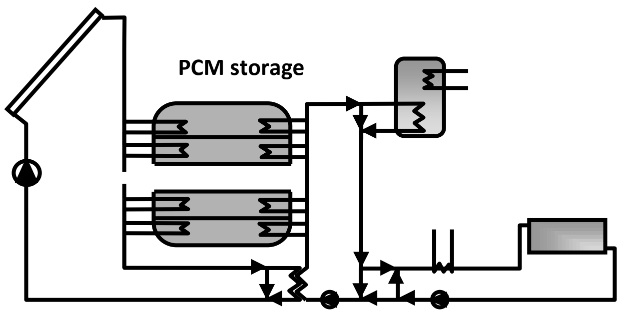


Energy content of sodium acetate compared to water as well as the super cooling process.

When the storage cools down from a temperature above the melting point it continues to cool down as a liquid following the dotted line. When the storage temperature reaches the surrounding temperature the storage becomes heat loss free. When energy is required the super cooled salt hydrate is triggered to solidify and the temperature rises almost immediately to the melting point. Some of the heat of fusion energy is used to increase the temperature of the salt hydrate from its super cooled temperature to the melting point, which is illustrated by the horizontal dotted line.

A seasonal heat storage based on the super cooling salt hydrate must be divided into a number of separate modules in order to achieve a heat loss free store since all salt hydrate in each module will solidify as soon as the salt hydrate is triggered in the module, see the figure.

The sodium acetate trihydrate storage is made up of a number of individual modules, which can be ed with respect to charging, discharging and activation of solidification if in a supercooled state. The purpose of separation into modules is to avoid activating the total volume of supercooled salt hydrate at one time, i.e. the modules make it possible to match the demand in a more efficient way.



Schematical sketch of solar heating system with seasonal PCM heat storage.

In an ongoing project Department of Civil Engineering will in the period 2009-2012 carry out the Danish part of the IEA project, International Energy Agency Solar & Cooling Programme Task 42 project "Compact Thermal Energy Storage: Material Development and System Integration". The project is financed by the Danish Energy Authority. The aim of the project is to develop and demonstrate a compact seasonal heat storage based on the above described principle. The heat storage can be a part of a solar heating system which can fully cover the yearly heat demand of new buildings in Denmark. A seasonal heat storage based on sodium acetate trihydrate will be developed and tested in a laboratory test facility. The development will be divided in a number of separate experimental and theoretical investigations which will elucidate how best to design the heat storage.

Among other things answers to the following questions must be found:

- Which container materials, container designs and container volumes will result in a stable supercooling of the heat storage material?

• Which heat storage temperature level is needed during charge periods in order to achieve a stable supercooling of the heat storage material?

• How does the heat storage design influence the heat exchange capacity rate during charge and discharge of the heat storage? Among other things CFD calculations will be applied.

• How are large quantities of sodium acetate trihydrate best filled into the containers of a store?

• How is the supercooled salt solution activated in the most reliable way?

• What is the optimum size of each module consisting of one separate container of the heat storage?

• Which control system is most suitable for the heat storage?

Based on the above mentioned investigations a laboratory seasonal heat storage will be built and tested in a laboratory test facility. The operation of the heat storage will be simulated as if the heat storage is a part of a solar heating system: The heat storage will be charged during a spring and summer period and discharged during an autumn and winter period. A simulation model simulating the thermal performance of the heat storage will be developed and validated by means of the measurements. The simulation model will be a special component within the TRNSYS program. With the validated model calculations of the thermal performance of solar heating systems with seasonal heat stores will be carried out in order to determine optimum designs of solar heating systems inclusive seasonal heat stores.

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Solar heating in Greenland

PhD student: Janne Dragsted *Supervisor: Simon Furbo*

Introduction

There are several advantages of using solar heating systems in Greenland compared with Denmark. For instance, in the summer where there is a lot of solar radiation, there is also a need for space heating which in part can be coved by solar energy. What is also important is that at high latitudes the optimum tilt of the collectors is increased, which increases the efficiency of the collectors. The reflection from the snow is also an important factor for solar heating in the Arctic.

The purpose of this PhD study is to investigate solar radiation in Greenland, and investigate how best to design solar heating systems for the Arctic climate.

Several studies will be carried out during the PhD.

Some of these are:

Reflection from the snow

The reflection from the ground is an important factor in the Arctic. Since snow is a good reflector and the ground is covered with snow in large parts of the year an accurate representation of the reflection is important to estimate the influence on the performance of a solar heating system in the Arctic.

Based on analyses of measurements from a Solarhat positioned in Sisimiut, Greenland, reflection from North, South, East and West is determined, see figure 1.

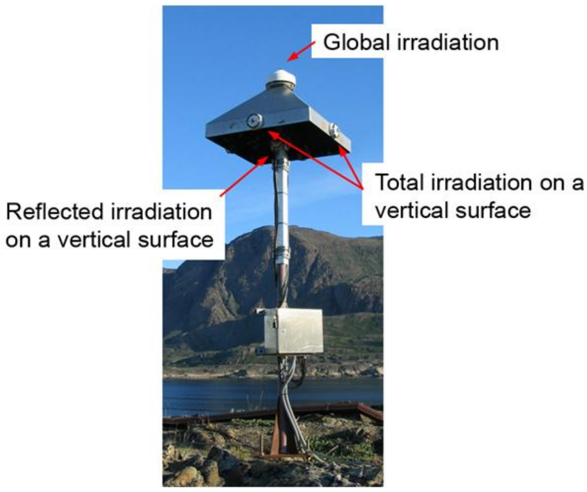

Fig. 1: Solarhat in Sisimiut.

The effective albedo based on the measurements in each of the cardinal directions can be seen in Fig. 2.

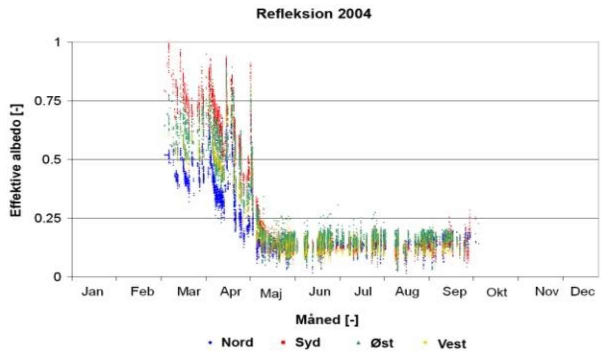

Fig. 2: The Effective albedo 2004.

The radiation from the sun is reflected mostly forward in periods with snow, see Fig. 3.

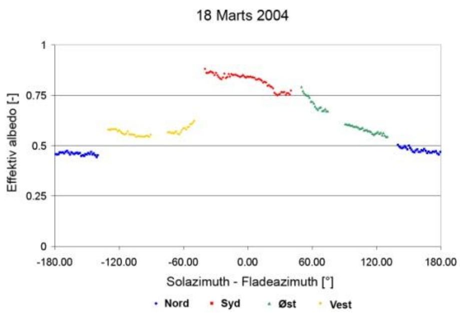

Fig. 3: The reflection when the ground is covered with snow.

In periods without snow the solar radiation is mostly reflected backwards, see Fig. 4.

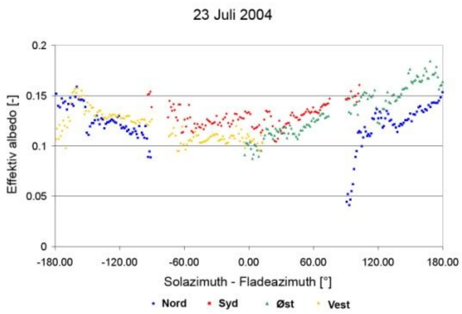

Fig. 4: The reflection when the ground is not covered with snow

Analysis of radiation models

In Greenland all settlements are located by the coastline and mostly on the western part of Greenland. This means that there is an added contribution of solar radiation in the reflection from the sea. This is also seen in Denmark in both Skagen and on Bornholm. Along with the reflection from snow covered ground, there seems to be a higher amount of diffuse radiation in Arctic regions. Therefore the accuracy of commonly used radiation model is investigated based on measurements of the global radiation and the diffuse radiation from the summer 2007.

Fig. 5: Global radiation measured in Sisimiut, Greenland.

Fig 6: Diffuse radiation measured in Sisimiut, Greenland.

On Fig. 7 the measurements from the 13 of August is shown. The dip in the global radiation is due to shadow cast by the Solarhat.

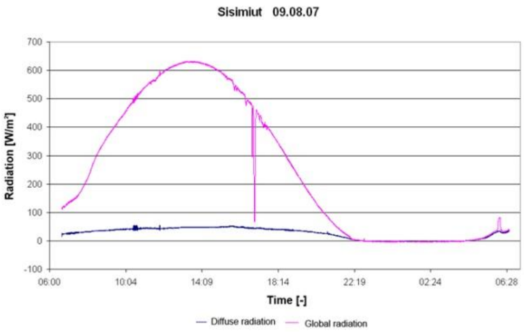

Fig. 7: Measurement of the global and diffuse radiation.

Analysis of evacuated tubular solar collectors

In the summer then sun is on the sky 24 hours a day in regions above the Arctic Circle. This makes the evacuated tubular solar collectors perfect since they can utilize solar radiation from all directions. Also the heat loss is decreased because the tubes are evacuated. At a test facility at DTU the efficiency of different evacuated tubular collectors is measured.

Fig. 8: The test facility at DTU Byg.

The performance of the same collectors is then simulated at high latitudes using the simulation program TRNSYS in order to investigate their suitability in the Arctic climate.

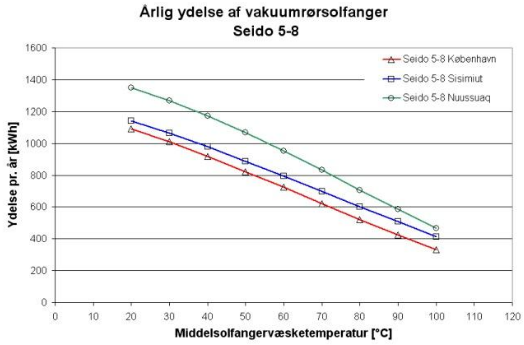

Fig. 9: The performance of evacuated tubular collectors simulated in TRNSYS.

Knud Rasmussen high school

In summer of 2008 Knud Rasmussen High School in Sisimiut, Greenland was equipped with a solar heating system with both evacuated tubular solar collectors and flat plate collectors. The first of its kind. The system is designed to cover the domestic hot water during the summer, and in periods with excess heat, supply parts of the building with space heating, see figure 9 and 10.

Fig. 9 Knud Rasmussen high school.

The system is installed with a large monitoring system for further investigations of the performance of the system.

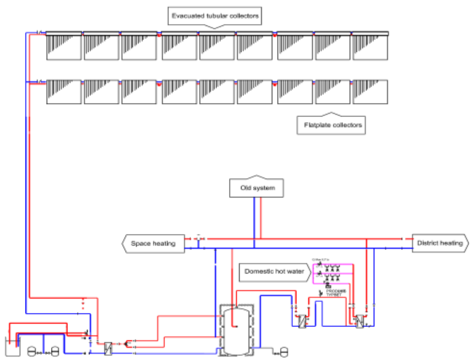

Fig. 10 Sketch of system at Knud Rasmussen high school.

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Stagnation in solar collector loops with large expansion vessels

PhD student: Janne Dragsted in cooperation with Simon Furbo and Bengt Perers

Purpose

The purpose of the project is to investigate solar collector loops with large pressurized expansion vessels and a control system which turn off the circulation pump in periods with critical high temperatures. The solar collector fluid will evaporate in the solar collector and the expansion of the evaporated fluid will press solar collector fluid into to the expansion vessel. In this way the system and the solar collector fluid will not be destroyed in sunny periods without heat demand.

Based on measurements guidelines for how to best design a solar collector loop will be described. The guidelines should focus on the appropriate volume of the expansion vessel for a certain system and what the pressure in the expansion vessel should be. The project is carried out in a cooperation with Batec Solvarme A/S.

Design and monitoring

At the test facility a system is installed in order to test the conditions in the solar collector loop.

In Fig. 1 a sketch of the system is shown. It is designed in such a way that it is possible to run four different tests.

1. One BA30 collector and direct connection
2. One BA30 collector and an U-connection
3. Three BA30 collectors and direct connection
4. Three BA30 collectors and an U- connection

For each test it is important to follow numerous values in stagnation periods. Altogether 69 different values are logged with an interval of 10 seconds.

These values are:

- 63 temperature measurements, where 48 are inside the collectors at the top and bottom of each manifold in the collectors, the rest are positioned on the pipes to and from the collector.
- 2 measurements of the pressure inside the system, near the collectors and close to the expansion vessel.
- The mass of the expansion vessel is measured, and in this way the increase or decrease of solar collector fluid in the vessel is determined.
- Total and diffuse solar radiation on the collectors.
- Ambient air temperature.

One a regular basis the Ph-value of the fluid is monitored along with the glycol percent of the vapour during the stagnation.

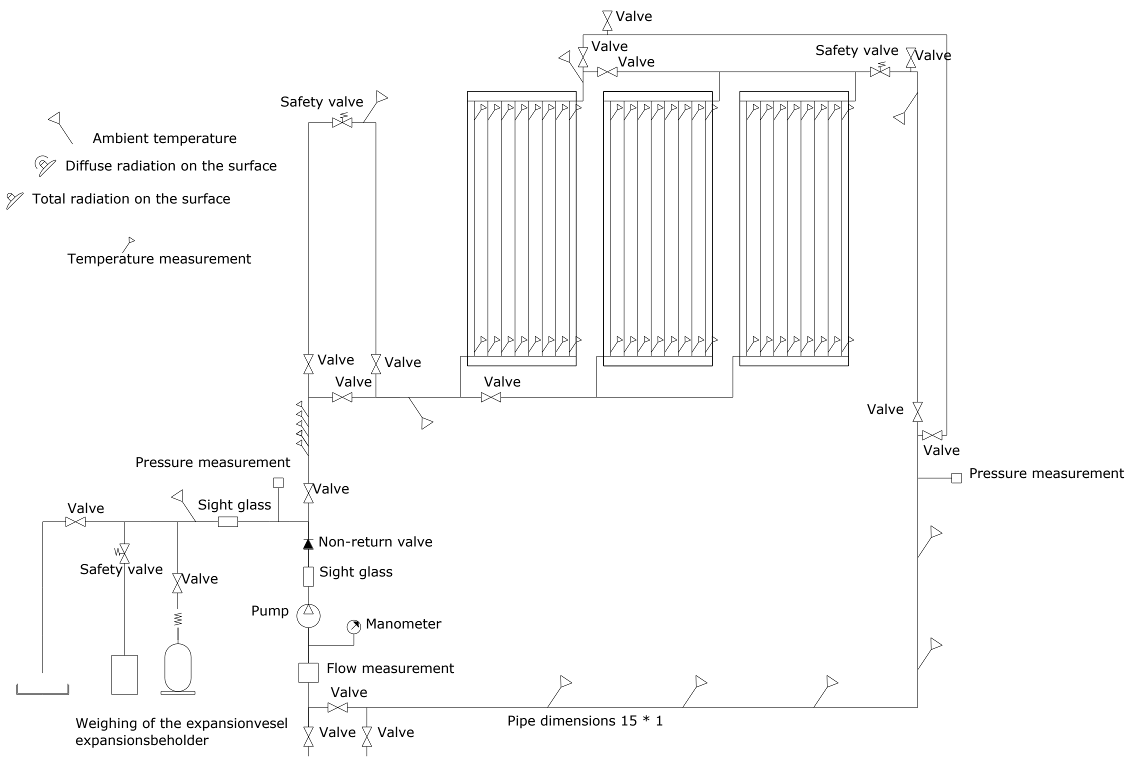

Fig. 1: Sketch of the system installed at DTU Byg.

System

The system is installed at the test facility at DTU Byg. On Fig. 2 the system is seen with the expansion vessel in the middle hanging from the weight. The 'black' dots in the system are the sight glasses where it is possible to view the fluid inside the system

Fig. 2: System installed at BYG DTU.

On Fig. 3 the collectors are seen, where two of the collectors are covered with a tarp, because the current test is with only one collector running.

Fig. 3: Collectors with only one collector in use.

Status

Measurements started in the middle of July 2009 and they will be continued until April 2010.

On Fig. 4 measurements of the weight of the expansion vessel and the pressure in the bottom and top of the system are shown for July 21, 2009. It can here be seen that stagnation starts around 11:30 and lasts until 15:30.

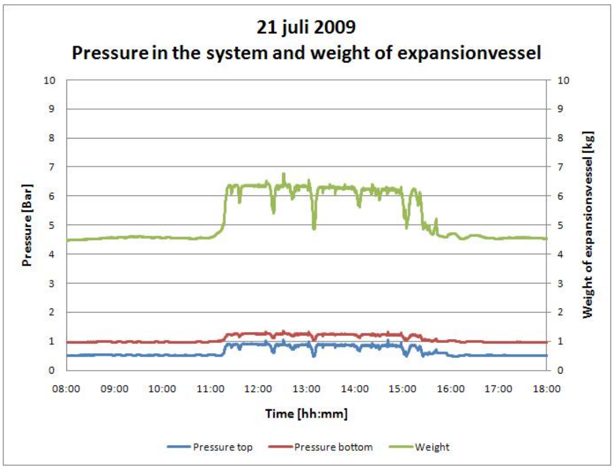

Fig. 4: The weight of the expansion vessel and pressure in the system.

On Fig. 5 two samples from the system can be seen. The one on the left is from the system when there is no stagnation in the start of the test period. The one on the right is taken from the system during stagnation. The sample is taken at the outlet of the collector, which means it is the vapor that has been collected.

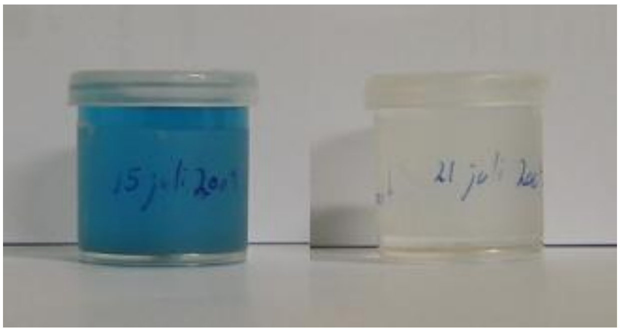

Fig. 5: Samples from the system extracted from the roof at the outlet of the collectors.

The measured glycol percent of the two samples are 32 % for the one on the left and 7 % for the one of the right. That means that the evaporated vapour has much lower glycol content than the solar collector fluid.

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Thermal performance of solar domestic hot water systems in laboratory tests

Research project: Elsa Andersen and Simon Furbo

During the period 1992 until 2008, 24 small solar heating systems have been tested side-by-side under realistic operation conditions in the pilot test facility at DTU Byg. Danish and foreign marketed systems as well as test systems have been tested Furbo (1998), Shah & Hansen (2002) and Andersen & Furbo (2008). The net utilized solar energy, determined by subtracting the auxiliary energy from the hot water consumption, is based on a domestic hot water consumption of 200 litres per day tapped in three equal portions at 7 am, noon and 7 pm. The domestic hot water is heated from 10°C to 45°C. The set point temperature of the auxiliary volume is 45.5°C. The system from Sonnenkraft Scandinavia A/S is a solar combi system and it is assumed that space heating is delivered at a temperature in the solar collector of 30°C. Table 1 show the results of the tests and in Figure 1 the same results are shown as the annual net utilized solar energy per m^2 solar collector area as function of the solar fraction. The solar fraction tells how large a part of the consumption that is covered by solar energy and is defined as the net utilized solar energy divided by the hot water consumption.

Manufacturer	Solar collector area [m^2]	Storage tank volume [l]	Characteristics	Annual net utilized solar energy [kWh]
Dansk Solvarme 1	4.00	290	High flow system with spiral tank	1353
Batec 1	4.38	295	High flow system with spiral tank	1453
Dansk Solvarme 2	4.02	280	High flow system with spiral tank	1472
Arcon Solvarme	5.02	250	High flow system with spiral tank	1671
Solahart Scandinavia 1	5.55	280	High flow system with spiral tank	1548
Thermo-Sol	3.33	280	High flow system with spiral tank	1545
Solenergi Kobbervarefabrikken	3.82	280	High flow system with spiral tank	1035
Batec 3	4.38	280	High flow system with spiral tank	1508
Aidt Miljø	4.83	265	Low flow system with mantle tank	1345
Batec 2	4.38	250	Low flow system with mantle tank	1492
Nordsol	4.02	265	Low flow system with mantle tank	1458
Test system 1	3.00	175	Low flow system with mantle tank	1319
Test system 2	3.00	175	Low flow system with mantle tank	1245
Test system 3	3.00	175	Low flow system with mantle tank	1201
Solahart Scandinavia 2	3.70	265	Low flow system with mantle tank	1455
AquaHeat	2.72	152	Low flow system with mantle tank	1326
Thermo Dynamics Ltd, Canada	5.56	270	Low flow pre heating system with external heat exchanger in the solar collector loop (Lifeline).	1643
ZEN B.V., the Netherlands	2.70	255	Drain back system with separat drain back vessel. High flow pre heating spiral and separate auxiliary heated tank.	1308

Bürgenmeier-Krismer Solartechnik, Switzerland	4.36	405	Low flow system based on Tank-in-tank. Solar collector loop of flextube.	1792
SolarNor, Norway	5.48	285	Drain back system. High flow system with spiral tank.	1357
Hoval-Solkit, Switzerland	4.20	470	Low flow system with mantle tank (two mantles). Solar collector loop of flextube.	1805
Batec Solvarme A/S	4.38	280	High flow system with spiral tank	1603
Velux Danmark A/S	4.30	300	High flow system with spiral tank	1258
Sonnenkraft Scandinavia A/S	4.41	300	High flow system with spiral tank. External heat exchanger for space heating.	1344+228

Table 1: Small solar heating systems tested in the laboratory in the period 1992-2008.

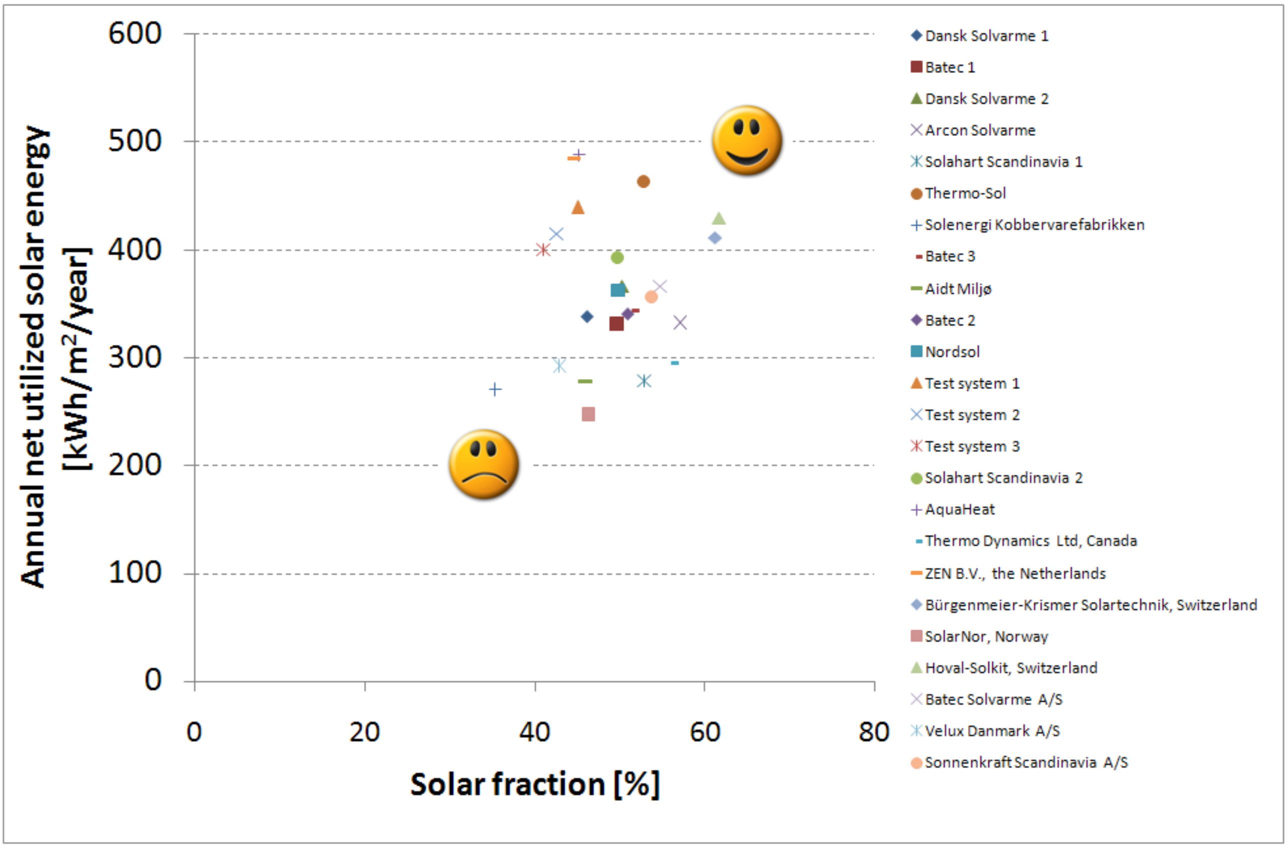

Fig. 1: The thermal performance of the tested small solar heating systems as function of the solar fraction. Good performing systems are situated in the upper right corner. Bad performing systems are situated in the lower left corner.

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Andersen, E. &Furbo, S. 2008: Solvarmeanlæg fra Batec Solvarme A/S, Velux Danmark A/S og Sonnenkraft Scandinavis A/S – målinger og beregninger. DTU Byg-report SR 09-01. ISSN 1601-8605.

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Smart solar tanks

Research project: Elsa Andersen and Simon Furbo

Theoretical and experimental investigations of small solar domestic hot water systems based on so-called smart solar tanks have been carried out. A smart solar tank is a tank where the auxiliary energy supply system heats up the hot water tank from the top of the tank and where the water volume heated by the auxiliary energy supply system is fitted to the hot water consumption and consumption pattern. Apart from a specially designed tank, also an advanced control system is needed. Figure 1 shows six smart solar tank designs, tank 1 – tank 6 and two traditional tank designs, tank 7 and tank 8.

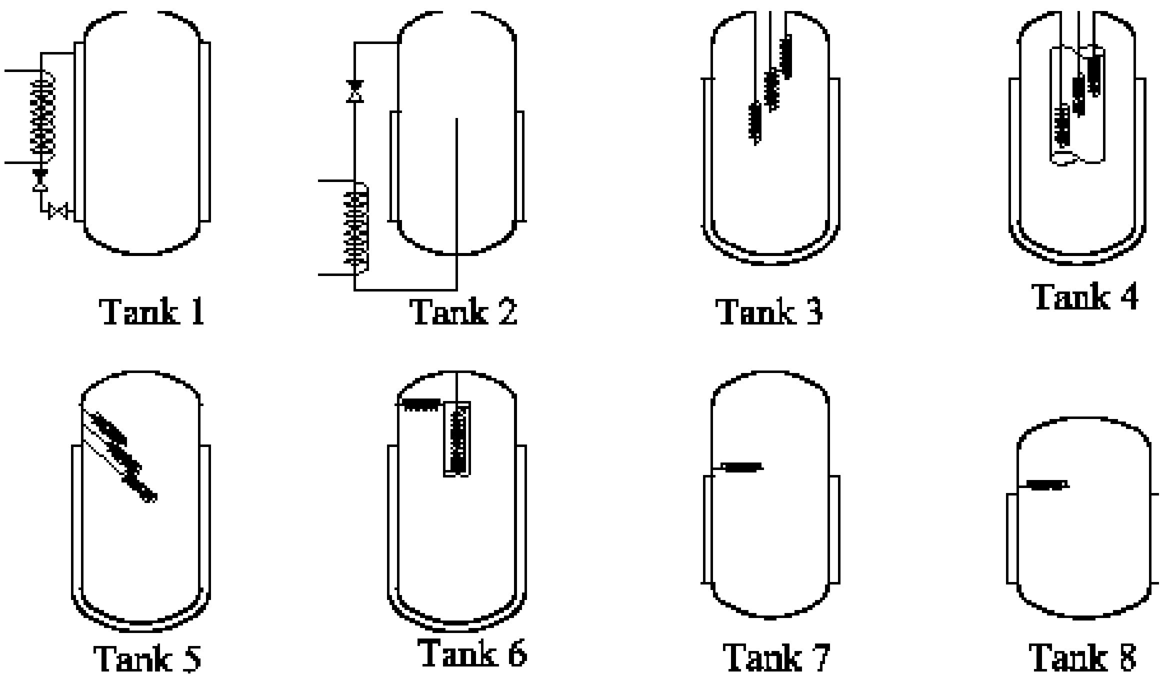

Fig. 1: Smart solar tanks (1-6) and traditional solar tanks (7-8).

In tank 1 and tank 2 water is circulated through a side arm by means of natural circulation initiated by the auxiliary energy supply system which is build into the side arm. In this way the tank is heated by the auxiliary energy supply system from the top of the tank. The heating is stopped when the needed volume is heated.

In Tank 3 – tank 6 the size of the auxiliary volume is controlled by heating elements, differently positioned in the tank. The heating elements can be activated independently of each other.

The position of the heating element in the traditional tank 7 and tank 8 determines the size of the auxiliary heated volume. Whenever the heating elements are active, the whole auxiliary volume is heated to a high temperature.

An advanced control system is needed that can register the energy content in the tank and the user needs to feed detailed information about the consumption pattern into the control system. As an alternative to the user programmed control system, the control system can be based on an adaptive system that within short time can recognize the consumption and the consumption pattern and adjust itself according to the consumption and the consumption pattern.

The investigations show that the thermal performance can by improved up to about 40 % by making use of a smart solar tank.

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Solar Combi Systems

Ph.D. project: *Elsa Andersen*

Introduction

The Ph.D. thesis, Andersen (2007), is based on ten publications. The publications describe different separate investigations with the aim to understand how solar combi systems work and which parameters have influence on the thermal performance of solar combi systems and the magnitude of the influence.

The publications

The first publication is about the thermal performance of solar combi systems in practice and in theory. Figure 1 shows the annual net utilized solar energy per m^2 solar collector as function of the solar fraction. All the dots represent measurements of systems in practice while the lines represent calculated thermal performances. A system situated in the lower left corner has a poor thermal performance while a system situated in the upper right corner has a good thermal performance. Figure 1 shows that the solar combi systems in practice perform as theoretically expected. This can be seen from the position of the measurements which lie between the theoretically good solar combi systems and the theoretically poor solar combi systems.

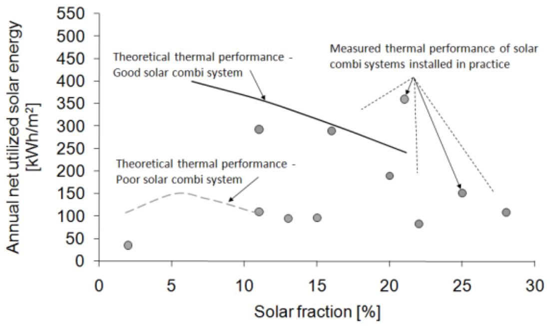

Fig. 1: Measured and calculated thermal performances of solar combi systems.

The second publication is a theoretical investigation of how varying measured weather conditions influence the thermal performance of different types of solar heating systems. Among others, it is shown that the utilization of solar radiation is higher for solar collectors with high efficiency than for solar collectors with low efficiency and that the utilization of solar radiation is almost not influenced by the varying amount of solar radiation from one year to another and that evacuated tubular solar collectors utilize less sunny years with large parts of diffuse radiation relatively better than flat plate collectors. Further as Fig. 2 shows, the total solar radiation on a 45° tilted south oriented surface cannot be estimated based on the global solar radiation because there is no linear relationship between these two. The linear relationship is especially poor during spring, autumn and winter months.

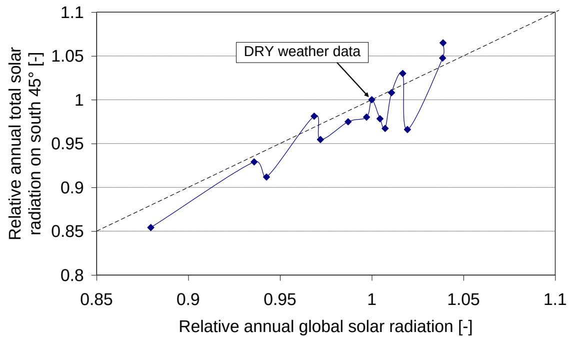

Fig. 2: The relative yearly total solar radiation on a south facing 45°-tilted surface as a function of the relative yearly global radiation.

The third publication is a theoretical and experimental investigation of different solar radiation processing models applied to Danish weather data. It is shown that anisotropic solar radiation processing models are better suited for calculating the radiation from horizontal to a tilted surface than isotropic solar radiation processing models. Anisotropic models assume that the intensity of the diffuse solar radiation is higher around the sun disc and in the horizon whereas the isotropic models assume that the diffuse radiation intensity is constant over the entire sky dome.

Most focus is put on thermal stratification both during discharge and charge and the thesis contains six publications on the topic. Stratified domestic hot water discharge can improve the thermal performance with 3 - 6 % depending on the solar heating system type and the set point temperature of the auxiliary volume while stratified space heating discharge can make the system independent of the reference conditions such as the return temperature from the space heating loop and thereby ensure that the thermal performance is not decreased due to mismatch between the system design and the reference conditions. Stratified charging by means of inlet stratification devices can improve the thermal performance up to 25 % compared to non stratified charging. As shown in Fig. 3, the thermal advantage by stratified discharge in the space heating loop and stratified charge in the solar collector loop strongly depends on the solar fraction of the solar heating system.

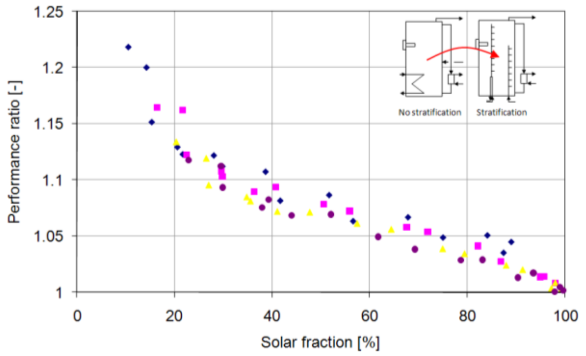

Fig. 3: Additional thermal performance as function of the solar fraction by using a stratified tank (right) compared to a non stratified tank (left).

During the Ph.D. project a new multilayer fabric inlet stratification pipe was invented and patented. Figure 4 shows a picture of a two layers fabric stratification pipe during a heating period where a cold tank is heated by means of hot water that is lead into the inner fabric pipe through the bottom of the tank. The fabric pipe is closed at the top. The fabric pipe equalizes the pressure difference between the hot pipe and the cold tank by contracting which can be seen in the lower part of the picture in Fig. 4. When the temperature in the pipe equals the temperature in the tank, the fabric pipe expands and water flows from the fabric pipe into the tank. This can be seen in the upper part of the picture in Fig. 4.

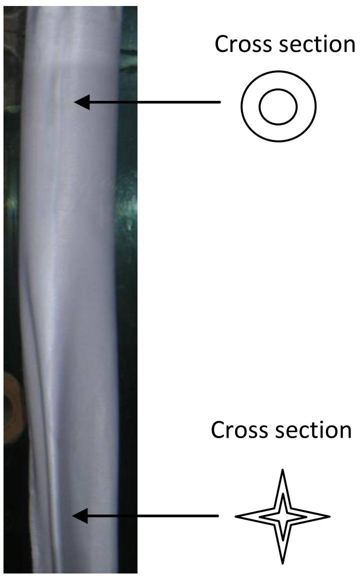

Fig. 4: A two fabric layers stratification pipe in operation.

Experimental investigations show that thermal stratification can be build up in a nearly perfect way by means of a fabric inlet stratification pipe made of two fabric layers. The optimal diameter of the inner fabric pipe is depending on the volume flow rate. The optimal diameter for low volume flow rates is small and large for high volume flow rates. Thermal stratification can be built up equally well with any flow rate as long as the optimal pipe diameter is used. The outer pipe diameter is approximately 20 mm larger than the inner pipe diameter. Using a two layers fabric stratification pipe corresponds to adding an insulating layer to the inner fabric pipe.

The last publication is about the influence on the thermal performance of pipes connected to the hot water storage tank. Figure 5 shows how much the thermal performance is decreased if there is a thermal bridge of a certain size in the top of the tank. It is also shown that apart from heat loss through the boundaries an additional heat loss occur due to a natural convection flow in the pipe where hot water from the tank flows into the pipe where it is cooled before it is exchanged with more hot water from the tank. The cooled water flows back into the tank and can cause a “water-fall” in the tank resulting in a destratification in the tank.

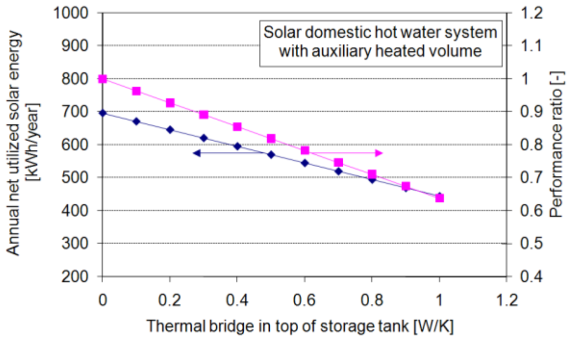

Fig. 5: Annual net utilized solar energy and performance ratio as function of the thermal bridge in the top of the tank.

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Inlet stratifiers

Research project: Elsa Andersen and Simon Furbo

Introduction

A well functioning inlet stratification pipe will lead incoming water of any temperature to the level in the storage tank with the same temperature. If the temperature of the incoming water is colder than any temperature in the storage tank, the water will be lead to the bottom of the tank and if the temperature of the incoming water is warmer than any temperature in the storage tank, the water will be lead to the top of the tank Andersen & Furbo (2006), Andersen, Furbo & Fan (2007), Andersen et al. (2007) and Andersen & Furbo (2008).

Many different inlet stratifier designs are found on the marked. Not all of the inlet stratifiers work as intended. During a heating period, it is of vital importance that water from the storage tank cannot be sucked into the stratifier due to a lower pressure in the inlet stratifier than in the tank since this will lead to a temperature destratification in the tank Shah, Andersen & Furbo (2005).

It is well known that the thermal performance of a solar heating system with highly stratified storage tank is much higher than the thermal performance of a similar system with a non stratified storage tank Andersen & Furbo (2007). Figure 1 shows the performance ratio as function of the solar fraction for differently sized solar combi systems located in different European climates. The net utilized solar energy is determined by subtracting the auxiliary energy from the hot water demand. The performance ratio is defined as the thermal performance of a system with a stratified tank (the right tank in Fig. 1) divided with the thermal performance of a system with a non stratified tank (the left tank in Fig. 1). The solar fraction is defined as the thermal performance divided with the domestic hot water and the space heating consumption. From the figure it can be seen that the performance ratio is high for solar combi systems with low solar fraction and it is seen that the performance ratio decreases for increasing solar fraction.

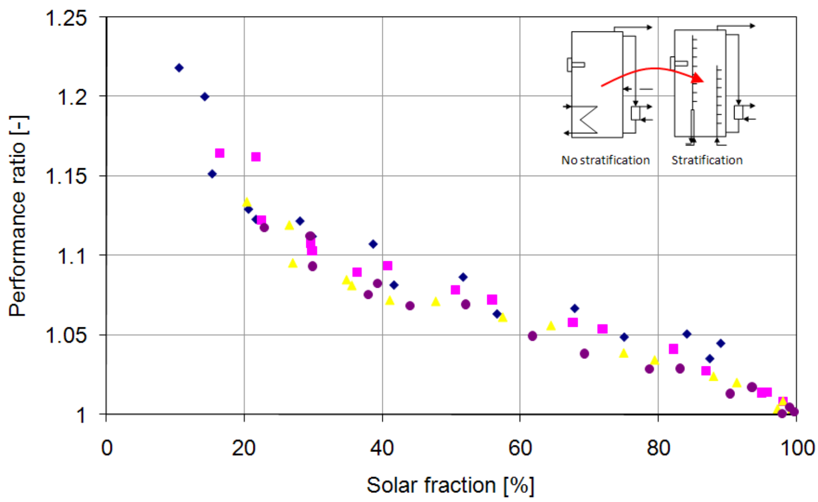

Fig. 1: The thermal performance advantage by using a stratified storage tank (right tank) instead of using a non stratified storage tank (left tank).

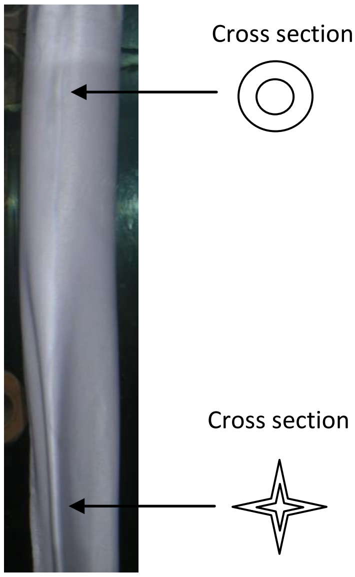

Fig. 2: A two layer fabric stratification inlet pipe in operation.

In 2006 a new inlet stratifier was developed and patented Andersen & Furbo (2006) and Andersen & Furbo (2008). The inlet stratifier is designed of two or more fabric layers. Figure 2 shows a picture of a two layer fabric inlet stratification pipe in operation. The fabric inlet stratifier is mounted in the centre of the tank and stretching from the bottom of the tank to the top of the tank. The fabric pipe is closed at the top. Water enters the fabric pipe through the bottom of the tank. When the temperature in the pipe is higher than the temperature in the tank, the fabric pipe contracts to eliminate the pressure difference between the water inside and outside the fabric pipe. Consequently, cold water from the tank is not flowing into the fabric pipe. A cross section of the contracted pipe is shown in the lower right corner of Fig. 2. The fabric pipe expands when the temperature in the pipe equals the temperature in the tank and water flows from the pipe into the tank. A cross section of the expanded pipe is shown in the upper right corner of Fig. 2.

Conclusions

Experimental investigations have shown that with a two layer fabric inlet stratifier:

- The optimal diameter of the inner pipe is a function of the volume flow rate
- The gap between the inner and the outer fabric pipe works as an insulating layer
- Almost perfect thermal stratification can be built up during operation
- Thermal stratification can be maintained during operation

Further advantages are:

- Inlet can take place in any level
- Easy and cheap to produce
- Easy to store and transport

Finally, a solar heating system with inlet stratifiers is less sensitive towards not optimal operation conditions than a traditional solar heating system with coil heat exchanger in the solar collector loop and direct return inlet from the space heating loop.

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Advanced solar combisystems

Ph.d. research project: Eshagh Yazdanshenas, 2006-2009

Introduction:

The solar heating market worldwide grows by 20-40% each year. In most European countries the percentage part of solar heating systems, which are solar combisystems is growing. Solar combisystems can cover both a part of the space heating demand and a part of the domestic hot water consumption. One of the most important studies on solar combisystems was done in the framework of Task 26 of IEA Solar Heating and Cooling programme between 1999 and 2002. Twenty one different solar combisystems were investigated numerically in detail in different IEA member countries. A design hand book for solar combisystems was published Weiss, [1]. In order to gain high energy savings for solar combisystems, it is important to have:

- A small auxiliary volume in the heat storage.
- A low auxiliary set point temperature of the auxiliary volume in the heat storage.
- A low tank heat loss
- A high efficiency of the auxiliary heater
- A good thermal stratification in the heat storage tank

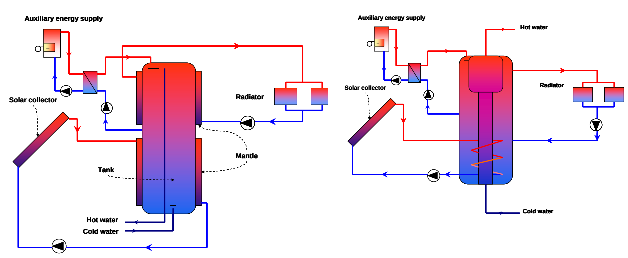
E. Yazdanshenas and S. Furbo [2] investigated theoretically a new so called bikini solar combisystem. Three different houses with four different radiator systems were considered. The thermal performance of the bikini solar combisystem was compared with the thermal performance of a solar domestic hot water system based on a mantle tank. The thermal performance of the solar combisystem in low energy houses is higher than the thermal performance of a solar domestic hot water system based on a mantle tank. The investigation also showed that a bikini solar combisystem is promising for low energy houses.

The current paper deals with the comparison of two different solar combisystems: Tank-in-tank solar combisystems and solar combisystems based on bikini tanks. The aim of the paper is to study which of these two solar combisystem designs is suitable for different houses. First the bikini tank as a single component was investigated experimentally in order to determine the heat exchange capacity rate for the upper mantle during discharge. Then a tank model in TRNSYS was validated by means of the experimental tests. The thermal performance of solar combisystems based on the two different heat storage types is compared.

Simulations:

Schematic sketches of the investigated solar combisystems are shown in Fig. 1. In the solar combisystem based on a bikini tank, solar heat is transferred from the solar collector fluid to the domestic water by means of a mantle welded around the lower part of a hot water tank. Heat is transferred from the domestic water to the water in the space heating system by means of a mantle welded around the upper part of the hot water tank. The domestic hot water is directly tapped from the tank.

In tank-in-tank solar combisystems, a domestic hot water tank is integrated in the space heating heat store. Solar heat is transferred by an internal heat exchanger spiral placed at the lower part of the tank. The space heating system is connected directly to the tank. Domestic hot water tank is tapped from the domestic hot water tank in the store.



a) Bikini solar combisystem

b) Tank-in-tank solar combisystem

Fig. 1. Schematic sketches of the investigated solar combisystems.

The average daily hot water consumption is 100 l with different hot water consumption patterns. Fig. 2 shows a strongly variable pattern used in IEA-SHC Tasks 26 and 32 [3]. The cold and hot water temperatures are 10°C and 50°C. The yearly hot water consumption is 1698 kWh/year. Both bikini tank and the tank-in-tank store have a height/diameter ratio of 4.

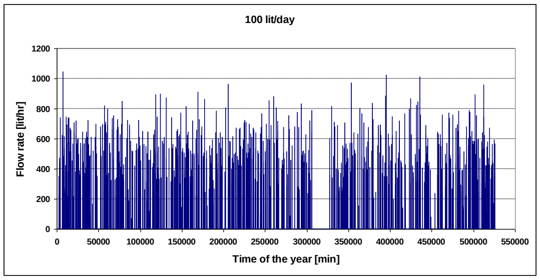


Fig. 2. Task 26 DHW profile during the whole year.

Three different houses with space heating demands of 5000 kWh/year, 9500 kWh/year and 16000 kWh/year are used for the simulations. The house area is 150 m². Fig. 3 shows the heat demand throughout the year (left) for the houses and the flow and the return temperature of the assumed space heating systems (right).

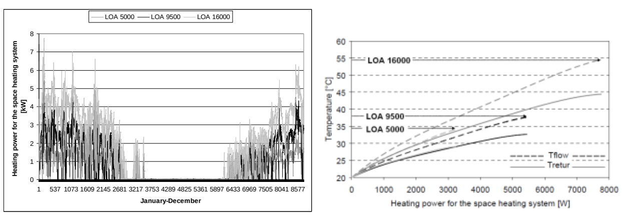


Fig. 3. Heat demand for three houses during the year and flow and return temperature of the space heating system.

Simulation results

Fig. 4 shows the net utilized solar energy of the solar combisystem installed in an old house, a house with medium space heating load and a low energy house for collector areas of 3, 5 and 8 m². The smaller the collector area, the better the bikini solar combisystems performs compared to tank-in-tank solar combisystems. For a collector area of 3 m², the net utilized solar energy increases for the tank-in-tank solar combisystem and decreases for the bikini solar combisystem as the space heating load increases. For the bikini solar combisystem, the set point temperature for the auxiliary heater is increased from 55°C for the low energy house to 60°C and 75°C for the houses with medium space heating demand and high space heating demand. For the tank-in-tank system, the auxiliary set point temperature remains constant at 59°C. It can be seen that bikini solar combisystems have higher thermal performance than tank-in-tank solar combisystems as long as the collector area is small. When the collector area increases, the thermal advantage of the bikini tank is decreased especially for houses with high space heating demands. The results are explained by the different required set point temperature for the auxiliary energy supply system.

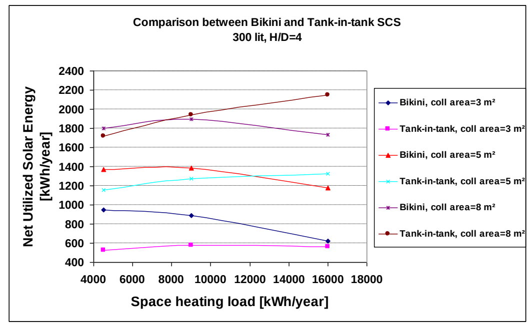


Fig. 4. Net utilized solar energy versus space heating demand for Task 26 DHW profile.

Conclusion

Solar combisystems based on bikini tanks and tank-in-tank stores have been studied. Bikini tank systems require, if installed in low energy buildings, low auxiliary volume set point temperatures resulting in high thermal performances. High auxiliary volume set point temperatures are required for bikini tank systems installed in houses with a high space heating demand. This results in a relatively low thermal performance. Bikini tank systems are therefore only suitable for low energy buildings with low temperature space heating systems while tank-in-tank combisystems are suitable for normal and old houses. The study has also shown that when the direct inlet from the space heating to the tank is replaced with an inlet stratifier in the space heating, the thermal performance will increase by 3-6%.

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Solar/electric heating system for the future energy system

Research Project: *B. Perers, S.Furbo, E. Anderssen, J.Fan*

Introduction:

Presently 20% of the electricity in Denmark is produced by wind power. It is expected that in the near future this share will be increased to 40%. This will require adapted use of electricity, to the availability and price of electricity in the grid. In the Nordic countries, a common electricity stock exchange NordPool exist that creates hourly electricity prices 24 hours ahead for all days of the year. By using this information and also weather forecasts, predictions of heat load and solar heat production, the price variations and a solar heating system using a smart controller and an advanced storage tank can be used to minimize the energy cost and utilize renewable energy sources in a better way in the future. The backup electricity can be used both in the form of direct electric heating of the tank or via a heat pump. The project is carried out in a cooperation between Department of Civil Engineering, Technical University of Denmark, Danish Meteorological Institute (DMI), DTU Informatics, Technical University of Denmark, ENFOR A/S, AllSun A/S, Ohmatex ApS, ~~and~~ Ajva ApS and COWI A/S,. At Department of Civil Engineering the above proposed solar heating system will be investigated by means of theoretical calculations and experimental studies.

The Simulation model: A TRNSYS system simulation model has been developed to simulate a single family house with a solar combi-system. The combi-system uses an electric backup controlled according to the weather and electricity prices. So far the control strategy and tank design is just at a first level.

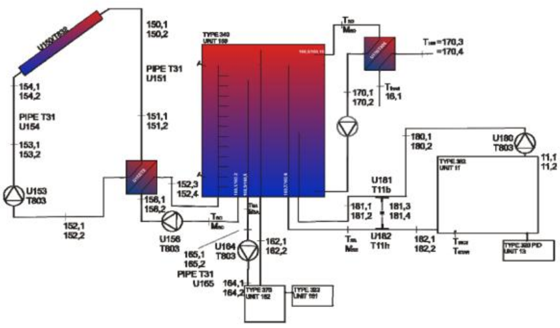

Fig.1: A simplified drawing of the system simulated with TRNSYS.

First Results: One first result is that even a normal solar heating system without smart control seems to benefit significantly from variable electricity prices compared to a fixed average price. This is mainly caused by the normal pattern for heating of a house. This is often largest during off peak hours. Smart control strategies and tank design will further reduce the energy cost for heating and hot water. Figure 2 shows a diagram of the monthly costs for heating with fixed and variable price and with and without solar. T~~In this case t~~he hot water load is ~~reduced to~~ 1~~1~~00 l/day which ~~that~~ is common in Denmark.

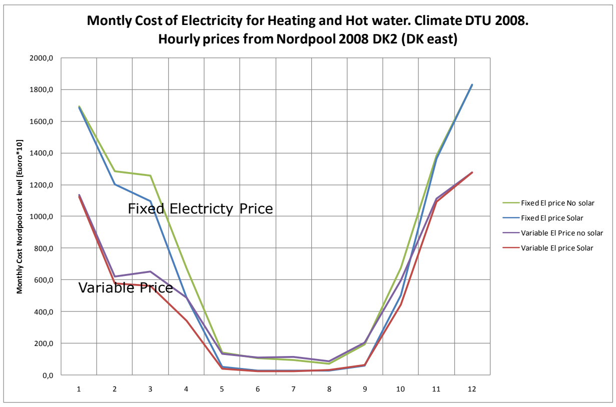

Fig. 2: Comparison of monthly costs for backup electricity with fixed and variable electricity price + with and without solar. Cost level at NordPool exchange level not final customer.

In figure 3 an optimization diagram for tank volume and collector area is shown. A system sizing of 10 m² collector and 500 l storage was chosen as a first estimation of optimum size. Further considerations will probably change this choise somewhat later on.

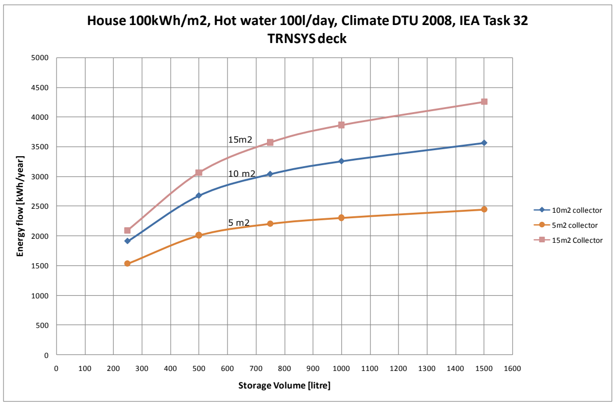

Figure 3. Optimization diagram for tank volume and collector area.

In figure 4 more detailed results are shown from a simulation as an example. This can be used to study how the tank reacts during charge and discharge and check that a good temperature stratification is maintained.

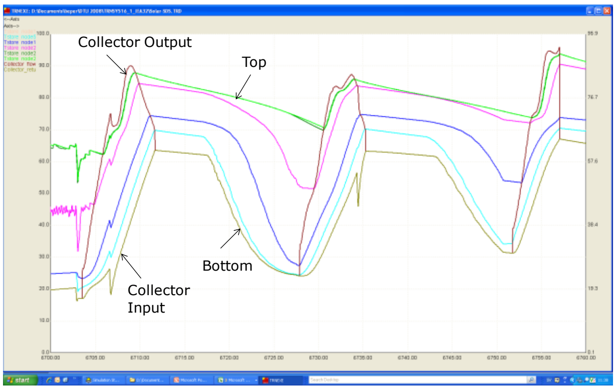

Figure 4. An example of stratification variations during a system simulation. These online plots from TRNSYS are very effective to check the system setup and operation.

Climate Data: Climate data from the weather station at Department of Civil Engineering, Technical University of Denmark~~ in Copenhagen~~ has been used together with Nordpool electricity data for the same period (2008) and area (Denmark East) in the TRNSYS simulations. This gives a realistic situation in the simulations and also different control strategies can be evaluated with exactly known prognosis data if desired. Figure 4 gives an example of some of the weather variables that are used in the simulations.

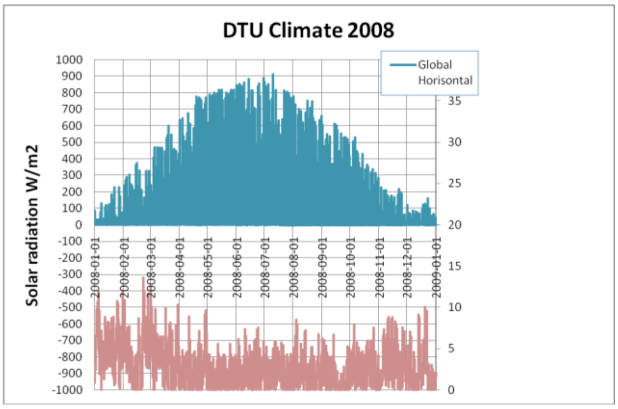

Figure 5. Example of climate data from the weather station at Department of Civil Engineering, Technical University of Denmark for 2008. The lower curve is wind speed with axis to the right.

NordPool electricity cost data: The electricity price is determined each day at the electric stock exchange NORDPOOL. Historical data some years back has been derived and transformed so that TRNSYS can read and use the data in the simulations. Especially in west Denmark with the highest fraction of wind power the prices vary very much during the day and the year. Figure 6 shows an example of the hourly price variation for one year. The high peaks often occur during the day and the low prices in the early morning. Figure 7 shows the daily average prices for three years for Denmark West. It can be seen that the prices vary much from year to year too. There is also a day by day pattern that may be used with a larger storage in the solar combi system.

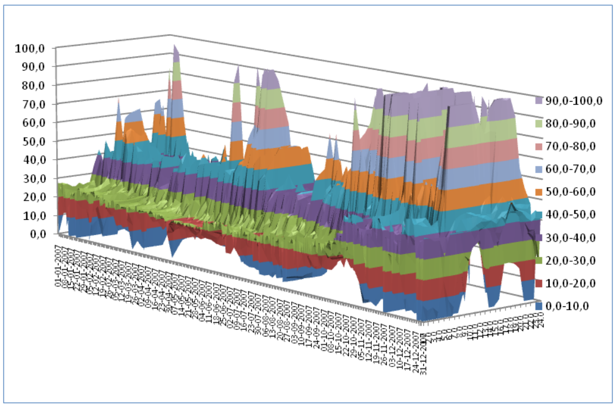

Figure 6. Example of the daily electricity price variations during one year in western Denmark.~~,~~ The unit on the y-axis is Euro/MWh at production plant.

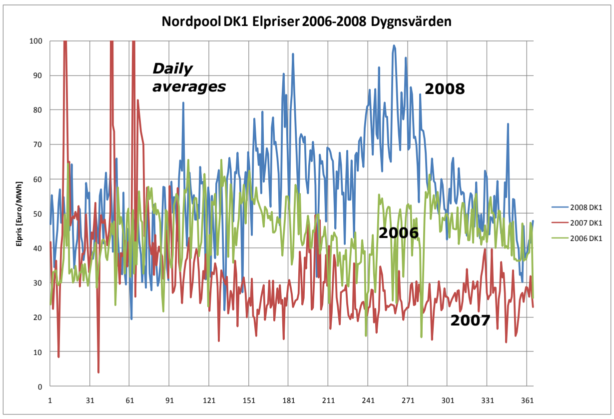

Figure 7. Example of the daily electricity price variations during one year in western Denmark. The unit on the y-axis is Euro/MWh at the production plant.

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Nordpool homepage: www.nordpool.com

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Experimental Investigations on Small Low Flow SDHW Systems Based on Mantle Tanks

Jianhua Fan, Simon Furbo

Introduction

Theoretical investigations show that it is possible essentially to increase the thermal performance of low flow solar domestic hot water systems based on Danish marketed mantle tanks by relatively simple design changes of the tanks (Furbo and Kundsen, 2006). The thermal performance can be strongly improved by:

- Increasing the height/diameter ratio of the mantle tank
- Reducing the height of the mantle
- Increasing the thickness of the insulation material on the tank side
- Placing the mantle inlet at a level somewhat lower than the upper mantle level
- Using a tank material with a lower thermal conductivity than steel

In order to document that marketed mantle tanks can be improved as mentioned above, tests were carried out in a laboratory test facility for solar domestic hot water systems at the Technical University of Denmark. Two small low flow solar domestic hot water systems based on mantle tanks were tested side-by-side in the test facility. The systems are identical with exception of the mantle tanks. The most important data for the systems are shown in table 1.

TABLE 1: Data for the two tested solar heating systems

Solar collector manufacturer	Arcon Solvarme A/S
Solar collector type	ST-NA
Solar collector area	2.51 m²
Maximum collector efficiency	0.801
Collector heat loss coefficients	3,21 W/m²K and 0.013 W/m²K²
Incidence angle modifier for collector	3.6 (tangent equation)
Collector orientation	South facing
Collector tilt	45°
Solar collector loop	33 m 10/8 mm copper pipes
Volume flow rate in solar collector loop	0.5 l/min
Solar collector fluid	40% propylene glycol/water mixture
Location	Technical University of Denmark, Kgs. Lyngby, Denmark. Latitude: 56°N

Experiments

Both hot water tanks have a total volume of 189 l and an auxiliary volume of 86 l at the top of the tank heated to 51°C by a 1000 W electrical heating element during the tests. The hot water tank diameter is 492 mm and 400 mm for the Danlager 1000 tank and the test tank respectively. The height/diameter ratio for the hot water tank is 2.1 for the Danlager 1000 tank and 3.9 for the test tank. The mantle inlet for the Danlager 1000 tank is located at the very top of the mantle, while the mantle inlet for the test tank is located 125 mm from the top of the mantle. Both tanks are insulated with PUR foam insulation filling up the space between the tanks and the cabinets. Consequently the insulation thickness for the test tank is greater than the insulation thickness of Danlager 1000. The tests were carried out with the same daily hot water consumption of 100 l/day. Figure 2 shows a photo of the two tanks used in the investigations. The most important data for the two mantle tanks are shown in table 2.

Fig. 2. Photo of the two tanks used in the experiments.

TABLE 2: Data for the two mantle tanks of the solar heating systems

Tank	Danlager 1000	Test tank
Outer diameter of hot water tank	0.492 m	0.400 m
Height/diameter ratio of hot water tank	2.1	3.9
Mantle gap	0.0115 m	0.0200 m
Mantle height	0.395 m	0.600 m
Heat transfer area, mantle	0.61 m²	0.75 m²
Water volume above upper mantle level	97 l	110 l
Mantle inlet	Top of mantle	0.125 m from top of mantle
Thickness of hot water tank wall	0.0030 m	0.0025 m
Thickness of mantle wall	0.0025 m	0.0025 m

MEASURED THERMAL PERFORMANCE

The two solar heating systems have been tested under the same test conditions in the test period March 12, 2006 – May 22, 2007: The solar radiation on the two collectors is the same and the hot water consumption and hot water consumption pattern are the same for both systems. Hot water is drawn from the tanks at 7 am, at noon and at 7 pm in three equally sized volumes. The hot water consumption is 32.2 kWh per week.

The tapped energy, the auxiliary energy and the solar heat transferred to the heat storage are measured for each system during the whole test period.

The monitoring system had failures in some of the weeks during the test period. In the year May 08, 2006 – May 08, 2007 measurements of the thermal performance of the two systems were carried out in 40 weeks. Most of the weeks with failures of the monitoring system appear in the autumn 2006. The measured results for the 40 weeks are shown in table 3. The net utilized solar energy is the tapped energy minus the auxiliary energy transferred to the top of the tank by means of the electrical heating element. The solar fraction is the ratio between the net utilized solar energy and the tapped energy.

TABLE 3: Measured energy quantities in 40 weeks in the test period May 08, 2006 - May 08, 2007

Measured energy	Solar heating system with Danlager 1000	Solar heating system with test tank
Solar radiation on solar collector	2270 kWh	2270 kWh
Tapped energy	1289 kWh	1289 kWh
Auxiliary energy to top of tank from electrical heating element	738 kWh	664 kWh
Solar heat transferred to hot water tank	780 kWh	814 kWh
Net utilized solar energy	551 kWh	625 kWh
Solar fraction	43 %	49%

It is seen that the thermal performance of the solar heating system with the test tank in the 40 weeks test period is 13% higher than the thermal performance of the solar heating system based on Danlager 1000.

Figure 3 shows the performance ratio, defined as the ratio between the net utilized solar energy for the solar heating system based on the test tank and the net utilized solar energy for the solar heating system based on Danlager 1000, as a function of the solar fraction for the solar heating system based on Danlager 1000. Each point in the figure represents the performance ratio for one week. For instance, a point with a solar fraction of 0.50 and a performance ratio of 1.20 corresponds to a week where the thermal performance of the solar heating system with the test tank is 20% higher than the thermal performance of the solar heating system with Danlager 1000 and where the solar heating system with Danlager 1000 covers half of the hot water consumption.

The extra thermal performance of the solar heating system with the test tank is strongly influenced by the solar fraction. The extra thermal performance is increasing for decreasing solar fraction. The thermal advantage of the test tank is therefore highest in the winter period, in less sunny periods of the year and in periods with a high hot water consumption.

Based on the measurements it is estimated that the extra yearly thermal performance, without problems with the monitoring system, would be 15%.

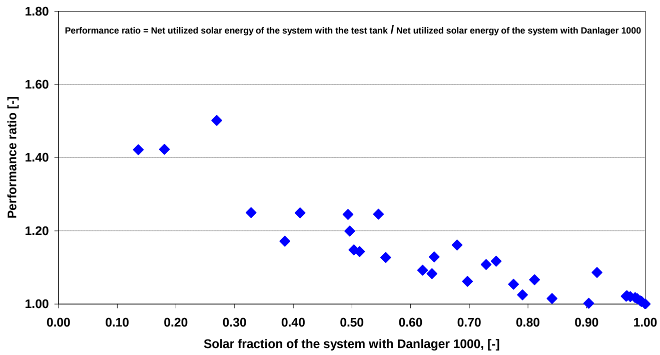

Fig. 3. Performance ratio for the solar heating system with the test tank as a function of the solar fraction of the solar heating system with Danlager 1000.

Conclusion

The measurements show that the thermal performance of a SDHW system can be increased by about 15% by replacing the marketed tank with the test tank.

It is thus documented that marketed mantle tanks can be strongly improved by increasing the height/diameter ratio, by increasing the thickness of the side insulation and by lowering the position of the mantle inlet.

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A Long Term Test of Differently Designed Evacuated Tubular Collectors

Jianhua Fan, Janne Dragsted, Simon Furbo

Introduction

During three years seven differently designed evacuated tubular collectors (ETCs) utilizing solar radiation from all directions have been investigated experimentally. The collectors have been investigated side-by-side in an outdoor test facility for a long period. During the measurements, the operating conditions – such as weather conditions and temperature of the inlet fluid to the collectors have been the same for all collectors. The volume flow rate through each of the collectors is adjusted so that the mean solar collector fluid temperature has been the same for all collectors. Thus a direct performance comparison is possible. The side-by-side tests were carried out with different mean solar collector fluid temperatures and in different seasons of the year. The results of the measurements are presented in this paper. The influence of the mean solar collector fluid temperature on the thermal performance of the different collector designs will be discussed. Further, the collector performances are compared for different times of the year and it is illustrated how the performance of the different collector types depends on weather conditions.

Experiments

Seven differently designed ETCs utilizing solar radiation from all directions have been investigated experimentally. Detailed data sheet of the investigated ETCs is given in Table 1.

Side-by-side tests were carried out in an outdoor test facility at the Technical University of Denmark, latitude 56°N, see Figure 1. On the test platform, five collectors can be tested under the same conditions at a time. The collectors are directly facing south and have a tilt angle of 67° which is suitable for typical operation conditions in the Arctic. The collectors can utilize solar radiation from all directions. A glycol/water mixture of 41% by weight is used as the solar collector fluid. The fluid flow rate through each of the collectors is measured by a flow meter type Brunata HGQ1-R0. The inlet and outlet temperatures of the collector are measured by copper/constantan thermal couples, type TT. The difference between the outlet and inlet temperature is measured by a thermopile. The accuracy of the absolute temperature measurement and temperature difference measurement is 0.5 K and 0.1K, respectively. The accuracy of the flow rate measurement is estimated to be 1.5%.

The thermal performance of the ETCs were measured in the period from February 2006 to August 2008. The experiment was divided into three phases:

Phase 1: February 2006 – June 2006, collectors tested: ETC 1, ETC 2, ETC 3, ETC 4 and ETC 5.

Phase 2: July 2006 – May 2007, collectors tested: ETC 2, ETC 4, ETC 5 and ETC 6.

Phase 3: May 2007 – August 2008, collectors tested: ETC 2, ETC 4, ETC 5, ETC 6 and ETC 7.

During the test period, four mean collector fluid temperature levels were used: 26°C, 43-47°C, 63-68°C and 75-78°C.

Fig. 1. The side–by-side test facility.

Thermal performance during the day

Figure 2 shows the collector power in an autumn day.

The direct flow ETC 7 performs almost the same as ETC 4 but in the early morning and the late afternoon ETC 7 performs a bit better than ETC 4. The all-glass ETC 5 on the other hand starts up slowly and stops almost 1 hour later than the other collectors. This is due to its large thermal capacity since a large quantity of collector fluid is stored in the glass tubes.

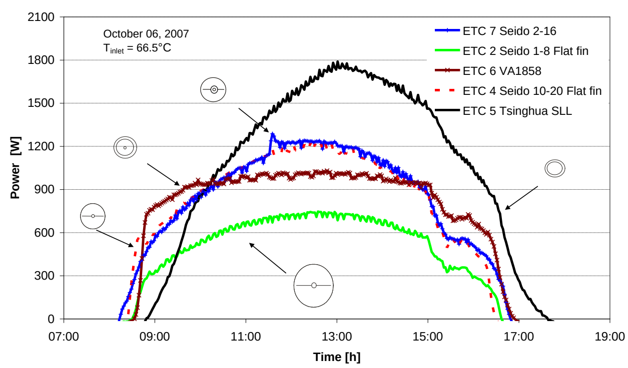


Fig. 2: Collector power in an autumn day in phase 3.

Long term thermal performance

The thermal performances of the seven ETCs are compared. Figure 3 shows relative thermal performances of the differently designed ETCs. The performance ratio is defined as the ratio between the weekly thermal performance of the collector in question and the weekly thermal performance of the reference collector shown in the figure. The mean solar collector fluid temperature during operation is given at the bottom of the figure. Detailed information of the thermal performances of the heat pipe ETCs, the double glass ETC, the double glass ETC with heat pipe and the direct flow ETC can be found in (Fan et al. 2007, 2008).

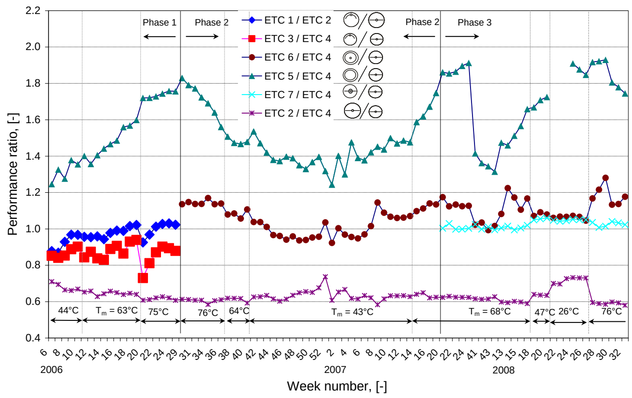
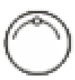
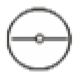
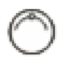
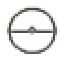
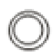
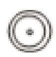


Fig. 3 Performance ratio of the differently designed ETCs.

Table 1. Data of the tested evacuated tubular collectors.

ETC no.	1	2	3	4	5	6	7
Collector type	Seido 5-8	Seido 1-8	Seido 10-20 with	Seido 10-20 with	SLL 1500	VA1858	Seido 2-16
Note	Vertical tubes,	Vertical tubes,	Vertical tubes,	Vertical tubes,	Horizontal tubes	Vertical tubes,	Vertical tubes,
Manufacturers	Sunda	Sunda	Sunda	Sunda	Tsinghua Solar	ExoHeat AB	Sunda
Number of tubes	8	8	20	20	50	24	16
Tube diameter	100 mm	100 mm	70 mm	70 mm	47 mm	58 mm	70 mm
Tube length	2000 mm	2000 mm	1750 mm	1750 mm	1500 mm	1800 mm	1700 mm
Tube centre	111-120 mm	111-120 mm	86-93 mm	86-93 mm	72-75 mm	79-84 mm	89-91 mm
Transparent area	1.54 m^2	1.54 m^2	2.36 m^2	2.36 m^2	3.30 m^2	2.45 m^2	1.87 m^2
Collector height	2.16 m	2.16 m	1.90 m	1.90 m	2.00 m	1.97 m	1.90 m
Collector width	0.96 m	0.96 m	1.86 m	1.86 m	3.20 m	1.99 m	1.82 m
Gross area	2.07 m^2	2.07 m^2	3.53 m^2	3.53 m^2	6.40 m^2	3.92 m^2	3.46 m^2
Absorber area	3.66 m^2	2.80 m^2	6.60 m^2	4.00 m^2	8.71 m^2	6.17 m^2	3.20 m^2
Absorber material	Aluminum	Aluminum	Aluminum	Aluminum	Glass	Glass	Copper-
Absorber thickness	0.47 mm	0.47 mm	0.6 mm	0.6 mm	-	-	0.6
Absorptance	0.92	0.92	0.92	0.92	0.90	0.92	0.92
Emittance	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Glass thickness	2.5 mm	2.5 mm	1.7 mm	1.7 mm	1.6 mm	1.6 mm	1.7 mm
Manifold diameter	28 mm	28 mm	38 mm	38 mm	45 mm	38 mm	38 mm
Symbol							

Conclusions

The observations from the measurements show that the direct flow ETC and the all-glass ETC have relatively high thermal performance m^2 transparent area. The all-glass ETC with solar collector fluid in the tubes and the double-glass ETC with heat pipe perform relatively better in summer than in the rest of the year. This behaviour is insignificantly influenced by the mean collector fluid temperature. The heat pipe ETC with flat fin performs better than the ETC with curved fin in most of the test period and the superiority will increase in winter periods and in periods with high mean solar collector fluid temperature.

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CFD/PIV Used in Solar Heating Research

Jianhua Fan, Elsa Andersen, Simon Furbo

Introduction

Solar energy is from a theoretical point of view the largest renewable energy source in the world. Solar heating can significantly contribute to cover the future energy demand. Already today solar heating systems cover the largest installed renewable energy capacity worldwide. Still there is a big potential to optimize the design and to improve efficiency of the solar heating system/component. Computational Fluid Dynamics (CFD) and Particle Image Velocemetry (PIV) can be used to investigate the fluid flow and heat transfer in the different components of the system, thus giving better understanding of the mechanism of the system /component.

The PIV test facility

At DTU.BYG the PIV equipment, Flow Map system from Dantec Dynamics, consists of a laser, a camera and a processing system for analysing the images taken by the camera. As an example, the experimental set-up for the test of inlet stratifiers is shown in Fig. 1. The set-up consists of a rectangular glass tank with side lengths of 400 x 400 x 900 mm^3, a heating and a cooling unit, and the PIV equipment. More details about the PIV equipment and the heating/cooling unit can be found in (Andersen et al. 2004).

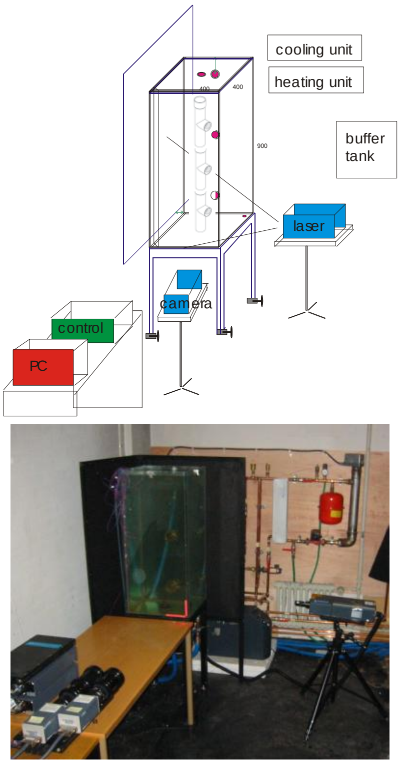

Fig. 1: the PIV test facility.

Heat transfer and fluid flow in a flat plate solar collector

As an important component of a solar heating system, solar collector panel converts solar energy into heat and transfers it to the solar collector fluid. If the solar collector panel should be improved, it is required that we understand the thermal behaviors of the collector panel under different conditions.

CFD calculations and thermal experiments are carried out to investigate flow distribution and heat transfer in a solar collector panel. The 12.53 m^2 solar collector panel type HTU from Arcon Solvarme A/S is designed for large solar heating plants. The collector panel consists of two vertical manifolds connected by 16 parallel horizontal absorber strips. Fig. 2 presents CFD calculated temperatures in the collector panel showing reverse flow in the top two strips (Fan and Furbo, 2008).

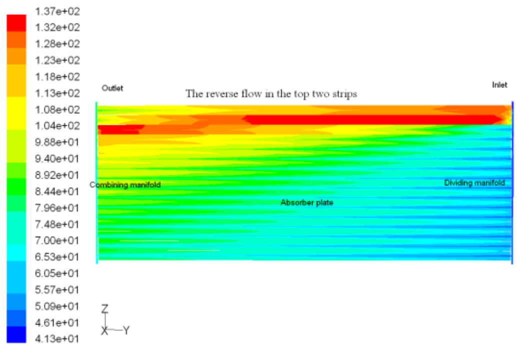

Fig. 2: CFD calculated temperature distribution (°C) at the middle plane of a flat plate solar collector.

Inlet stratifiers for a solar storage tank

Thermal stratification in a solar storage tank has a major influence on the thermal performance of the solar heating system. In solar combisystems, which are solar heating installations providing space heating as well as domestic hot water, very often diffuser manifolds or stratifiers, which should promote stratification, have been adopted. Generally, stratifiers are developed for variable inlet temperature and flow, corresponding to the conditions in the solar collector loop and the space heating loop of a solar combisystem. The main purpose for a stratifier is to allow the incoming fluid to enter the tank at the "right" height of thermal equilibrium.

One advanced stratifier design is shown in Fig. 3. At the openings there are mounted flaps, which work as "non-return valves". The flaps are constructed with a soft material which allows the flap to close and open depending on the temperature and pressure conditions inside and outside the pipe. The stratifier is designed by the German company SOLVIS GmbH, and according to the company the stratifier is suitable for flows up to 13 l/min. CFD/PIV is used to evaluate how a SOLVIS stratifier performs without non-return valves (Shah et al., 2005). Fig. 3 shows flow velocities in the tank obtained by PIV measurements and CFD calculations.

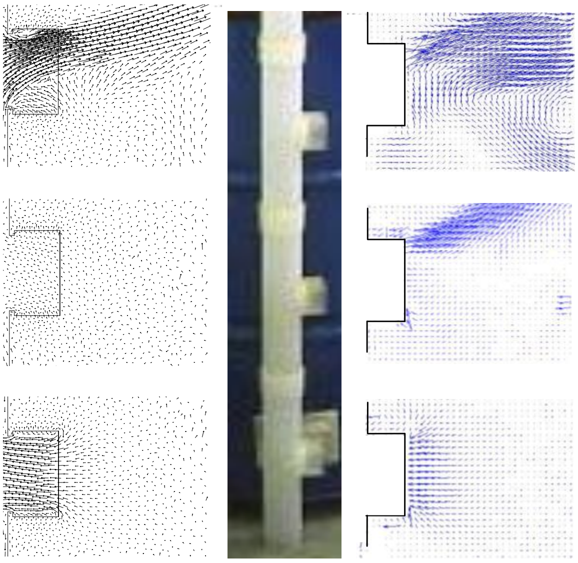

Fig. 3: Flow velocities for the stratifier without "non-return valves" obtained by means of PIV measurements (right) and CFD calculations (left).

Entrance effects in a hot water tank

The most effective way of avoiding destratification is to avoid water jets entering the tank. However, in most system designs, mixing to a certain extent cannot be avoided. A theoretical analysis of water jets entering a solar storage tank is performed by means of CFD calculations. It is elucidated how thermal stratification of the tank is influenced by the inlet water jets and how the thermal conditions in the tank are influenced by inlet design and inlet flow rate (Shah and Furbo, 2003).

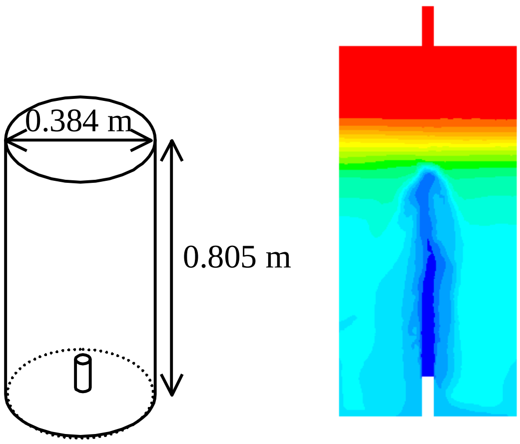

Fig. 4: Left: Sketch of the hot water tank with an inlet at the bottom. Right: Temperature contour of a hot water tank during a cold water inlet.

All glass evacuated tubes

Evacuated tubular solar collector is one of the most popular solar collectors in the solar heating market worldwide. Evacuated tubular solar collectors have many advantages such as:

- solar radiation from all around can be utilized, which makes it especially suitable for arctic regions where there is solar radiation coming from all directions (North, East, South, West) during the summer.

- low heat loss coefficient and are very suitable for low outdoor temperatures.

To improve the design of the collector, an understanding of both fluid flow and heat transfer inside the tubes under different conditions is necessary.

The heat transfer and flow structures inside all glass evacuated tubes are investigated for different operating conditions by means of CFD calculations. The investigations are based on a collector design with horizontal tubes connected to a vertical manifold channel (Shah and Furbo, 2007).

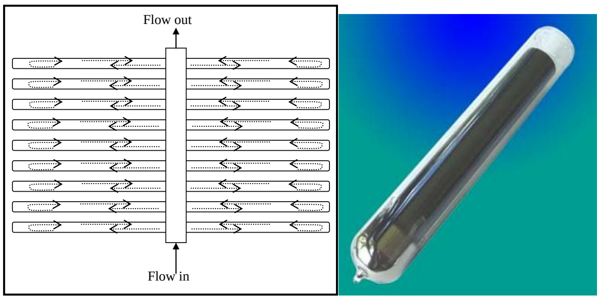

Fig. 5: Left: Sketch of flow in an all glass evacuated tubular collector. Right: An all glass evacuated tube.

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Solar Transmittances for Glass Covers With and Without Antireflection Treatment under Real Climatic Conditions

Ziqian Chen, Jianhua Fan, Simon Furbo

Introduction

Investigations have shown that the transmittance of a clean glass cover is increased by 5-9% by equipping the glass cover with antireflection surfaces by means of a liquid-phase etching by Sunarc Technology A/S. The increase from 5 to 9% depends on the incidence angle. The project has elucidated how much the transmittance for a glass cover can be improved in practice by antireflection treatment of the glass surfaces by outdoor long-term side-by-side laboratory measurements.

Methodology

The measurements were carried out in a test facility with four calibrated pyranometers, type CM 5 and CM11 from Kipp and Zonen. Before the tests started all 4 pyranometers were tested against each other after they have been put into position, but before the shadow ring and the glasses were installed to be sure they all gives the same output signal for the same solar irradiance. During the tests the pyranometers are measuring the total irradiance on the glasses, the diffuse irradiance on the glasses and the irradiances transmitted through two glasses, a normal glass and a glass with antireflection treatment. The accuracies of the measured irradiances are estimated to be within 2%. The glasses are placed side-by-side on a 45° tilted surface facing 10° towards west from south, see figure 1.

Figure 1. Test facility used to measure the solar transmittance of two glasses.

Left: Antireflection treated glass. Right: Normal glass.

Long-term Measurements of Transmittance

Measurements were carried out in the test period April 30, 2008 - February 15, 2009. As shown in Figure 2, measurements were not available for all days due to problems with the measuring equipment. Measured daily values for the total and diffuse radiation on the glasses are shown in figure 2. The daily rain amounts are shown as well. Figure 3 show the daily transmittances for both glasses. The daily transmittances are the ratios between the daily radiation transmitted through the glass and the daily radiation on the glass surface.

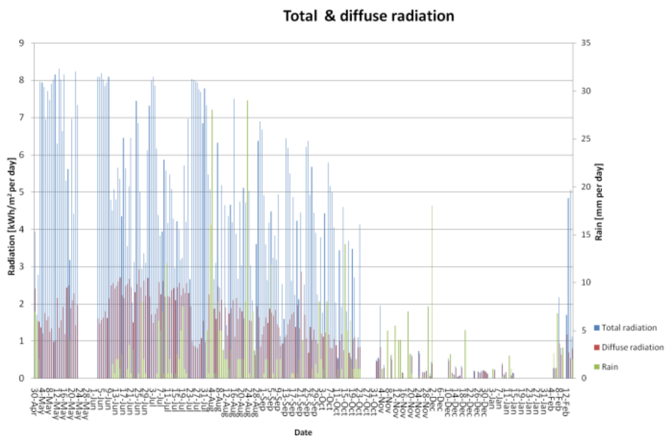

Figure 2. Measured daily total and diffuse radiation on the glasses and daily rain amounts.

The measured daily transmittances are varied from day to dayand during the test period. The variations from day to day are caused by variations in the weather with different ratios between the direct and diffuse radiation. Further, the daily transmittance for both glasses is relatively low in sunny days without rain. This might be caused by dirt attached to the glass surfaces. The daily transmittance for both glasses is relatively high in rainy days and in days after rainy days. This might be caused by the fact that the glasses are washed clean during rainy periods. The unrealistic very high and very low daily transmittances in the period November - February are caused by snow, which is either located on the glasses or on the pyranometers. The daily transmittances are lower in the summer period than in the winter period, especially for the normal glass. This is due to the fact that the incidence angle of the direct radiation is relatively low during the whole day in the winter, while the incidence angle in a large part of the day is relatively high during the summer.

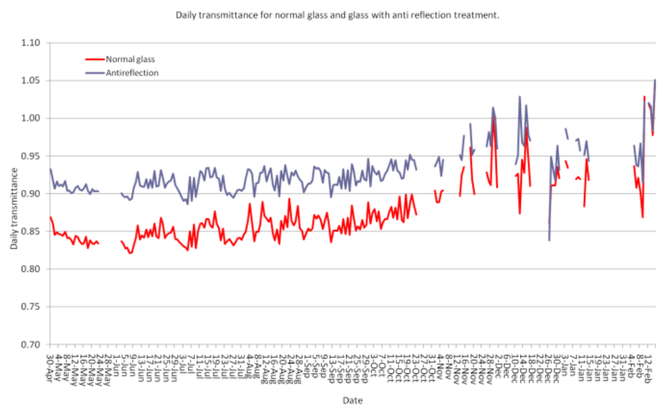

Figure 3. Measured daily transmittances for both glasses

For the whole test period the transmittances are 0.85 for the normal glass and 0.91 for the glass with the antireflection treated surfaces. The transmittance is for the whole test period increased by 7%, corresponding to 6 % points, by the antireflection treatment.

Measured and calculated daily transmittances for the two glasses are seen in figure 4. The calculations are based on transmittances for the clean glasses. Again it should be noticed that the unrealistic very high and very low measured daily transmittances in November-February are caused by snow. In most periods the measured daily transmittances are up to 5% lower than the calculated daily transmittances for both glasses. The difference between the measured and calculated daily transmittances is relatively large in sunny periods and relatively small in periods with and after rain. The reason is as mentioned, most likely that the glasses are washed clean during rain showers.

The ratio between the measured solar radiation transmitted through the glass and the calculated solar radiation transmitted through the glass for the whole test period is 0.98 for both glasses. That is: The transmitted solar radiation is reduced by 2% for both glasses due to dirt, water and snow on the glass surfaces. The reduction is higher in the summer than in the winter.

Considering the measuring accuracy it is concluded that the antireflection treatment has no significant influence on how much dirt, water and snow attached to the glass surfaces reduce the solar transmittance under Danish weather conditions.

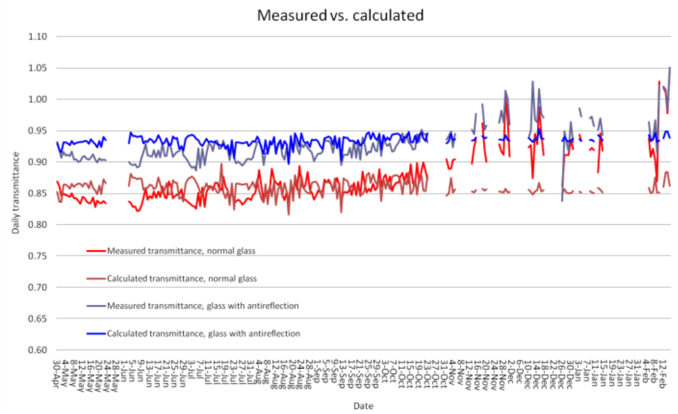

Figure 4. Measured and calculated daily transmittances for the normal glass and for the glass with the antireflection treated surfaces.

Conclusions

Long-term side-by-side measurements of the solar transmittance for a normal glass and a glass with antireflection treated surfaces show that the solar transmittance is increased by 7% by antireflection treatment under Danish weather conditions.

The measured transmittances for both glasses are 2% lower than the calculated transmittances based on measurements for the clean glasses. The antireflection treatment has, under Danish weather conditions no significant influence, negative or positive on the transmittance reduction caused by dirt, water and snow attached to the glass surfaces.

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5.3 Research activities in Building Physics

The research in hygrothermal building physics covers the mechanisms for coupled heat and moisture transport in and around the thermal envelope of buildings. The overall objective of the activities in this area is to establish and provide a basis for buildings with durable structures, buildings that are healthy to live in and require a minimum of energy for heating. Investigations are carried out on transport mechanisms in construction material, in ventilated cavities and near the internal and external construction surfaces, mainly when these are part of a complex thermal envelope. The competence within the area is for instance used to estimate the hygrothermal performance and the durability of well-known and new materials and structures for renovation and new building. Furthermore, the interaction between the structures and the indoor climate is analyzed, recognizing that moisture is one of the main causes for problems in the indoor climate.

Whole building heat, air and moisture assessment

Research project: Carsten Rode, Hans Janssen

Introduction

Moisture conditions in building constructions form central themes of study for researchers in building physics. Apart from experimental investigations into the subject, computer models predicting the conditions in the exterior constructions of buildings have been developed since at least the 1980'es. However, the conditions in the exterior constructions depend very much on the thermal and moisture conditions in the indoor and outdoor climates that surround the constructions. Moisture conditions depend very much on the temperature, and air that passes through or around a construction will have a significant impact on its heat and moisture performance. So Heat, Air and Moisture (HAM) conditions in constructions should be assessed simultaneously.

Heat and moisture conditions in the indoor environment are results of balances between heat and moisture being released by activities and processes in the rooms, and the rate by which it is cooled and dried as a result of air exchange with the outdoors or other environments, or with air that comes from an air conditions system. Naturally, in some case air may also come from an environment or system that is warmer or more humid than the rooms, in which case the air exchange will contribute to raising the temperature or humidity in the rooms. Important is to consider the sources of heat and moisture, such as from human activity, heat from solar gains, equipment and lighting, heat and moisture from activities such as cooking, bathing, laundering and drying of clothes and towels. Finally, of course, contributions from dedicated heating, cooling and humidifier/dehumidifier systems in rooms (as applicable) influence, or regulate, the temperature and moisture conditions in rooms.

However, predictions of the indoor heat and moisture conditions cannot be fully accomplished without considering the heat and moisture storage capacity, or buffer effect, of building constructions and inventory in rooms. Thus, the heat and moisture exchange needs to be considered, and in order to consider the storage terms, the calculations must be carried out using non-steady i.e. "transient", calculation methods.

All in all, a complex assessment is needed which must consider the coupled transport phenomena of heat, air and moisture; it should consider all constituents of rooms and how they are used and conditioned, and the construction and other materials which are kept within and adjacent to the rooms; and the assessment needs to integrate all of the above, and be transient.

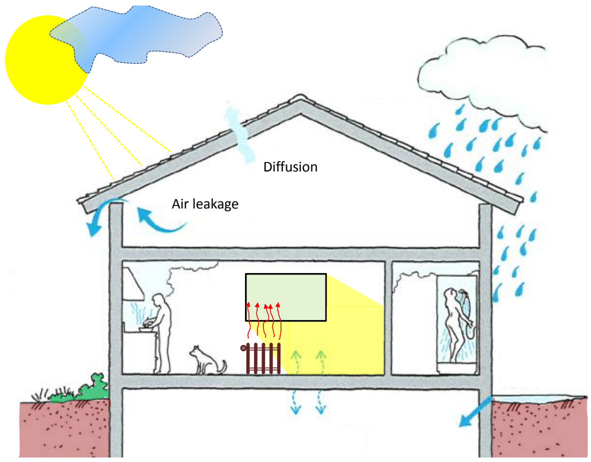

Figure 1: Illustration of some of the hygrothermal influences to be considered in a whole building assessment.

International Project

The above mentioned themes were studied in the recently completed joint international research project *Whole building heat, air and moisture response*, which was carried out as a so-called "Annex", namely *Annex 41* under the auspices of the International Energy Agency's (IEA) *Energy Conservation in Building and Community Systems Programme*.

The project started in the end of 2003, and was running for four years.

The project was organized in four subtasks:

Subtask 1: Modelling principles and common exercises

Subtask 2: Experimental investigations

Subtask 3: Boundary conditions

Subtask 4: Long term performance and technology transfer

The project had participation from researchers from 39 different institutions representing 19 different countries all over the world. Thus, the project has involved close to 100 researchers, including Ph.D.-students.

Operating Agent (overall project leader) for the project was Professor Hugo Hens from KU Leuven, Belgium.

Hans Janssen (KU Leuven and DTU Byg) has been the scientific secretary for the project.

Carsten Rode (DTU Byg) has shared responsibility for leading Subtask 1 with Monika Woloszyn (from INSA Lyon, France).

After completion of the project the final reports were published in spring 2008 (International Energy Agency, 2008). A public closing seminar about the project was held at DTU in June 2008 (Rode et al., 2008). After closing the project, its homepage is maintained open on: http://www.kuleuven.be/bwf/projects/annex41/, and working papers from the project are still accessible through that site.

Outline of the subtasks

Subtask 1 – Modelling principles and common exercises

The purpose of the subtask was to stimulate the participants to develop and test new simulation models to predict the integrated heat, air and moisture conditions for whole buildings. Since this can be a formidable modelling endeavour, many participants took a starting point either in existing whole building energy simulation tools and extended them with procedures to predict moisture conditions. Other participants extended some existing models for heat, air and moisture flow in individual building constructions with HAM balances for rooms and for several constructions surrounding the rooms. Finally, some participants used toolboxes, such as MATLAB/Simulink to develop small calculation modules that could be combined to perform an integral HAM analysis for a substantial part of a whole building.

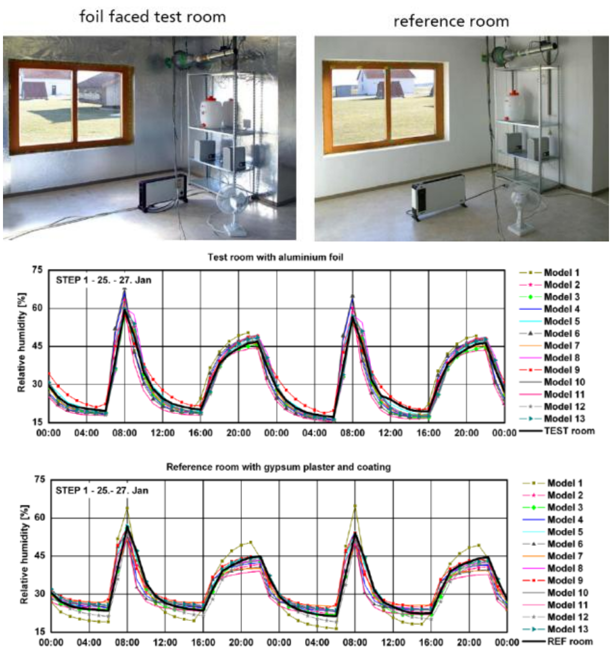

Figure 2. From Common Exercise 3: Two test rooms from field experiments of indoor air humidity at the Fraunhofer Institut für Bauphysik (Germany) and comparison of predicted results from different models.

The models were benchmarked in common exercises where the results were compared with other models or with experimental findings from field and laboratory tests. Some six different exercises were set up, executed and reported. An important purpose was also the provision of the exercises themselves so they could be available for other researchers to pick up and try. The exercises are accessible from the project home page.

Subtask 2 - Experimental investigations

This subtask dealt with round robin testing of hygrothermal properties of some common material specimens (gypsum). Water vapour transmission and sorption properties were determined on individual small specimens, and moisture buffering was tested on small, individual as well as on composite samples.

Subtask 3 - Boundary conditions

This subtask dealt with categorizing typical indoor moisture sources and humidity levels in buildings, accounting for various field investigations carried out in some of the participating countries. For the exterior side of buildings, focus was on wind-driven rain, air pressure coefficients, and solar and long-wave radiation.

Subtask 4 - Long term performance and technology transfer

This subtask gathered all the practical considerations regarding the subject matter of the project. Issues such as acceptable moisture levels, control strategies and safety aspects, and very importantly for the project as a whole as an IEA Annex: The influence on energy performance of buildings.

Closing remarks

The Annex 41 project has ambitiously given a contribution to solving a rather complex problem area, and has inspired a large number of participating researchers to contribute to this development. The project has uncovered difficulties in managing all the integrated aspects of whole building heat, air and moisture conditions. But it has also opened for some ways how to manage these issues and provide a lot of documentation that will be useful for the future's making of highly energy efficient, well performing, healthy and durable buildings.

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Assessment of moisture buffering by room enclosures

Research project: *Hans Janssen, Carsten Rode*

Introduction

The influences of interior humidity on the performance of building zones, building parts and building occupants are strongly multifaceted and highly interrelated. Interior humidity significantly affects the energy performance of building zones (via latent cooling loads and ventilation heating loads), the stability of building parts (via biological activities of fungi and moulds), and the health and comfort of building occupants.

Interior humidity is governed by interior moisture sources, moisture transport by ventilation air and moisture exchange with the room enclosure. The latter occurs in all enclosure elements, both interior finishes and interior objects (furniture, carpets, drapes, books, etc). Several authors indeed show that moisture buffering positively affects energy consumption, component durability, thermal comfort and air quality. Every development of sustainable, durable, healthy and comfortable buildings thus requires a quantitative and qualitative assessment of interior moisture buffering.

Qualitative assessment

Single-finish MBP characterisation

Japanese Industrial Standard A 1470-1, Draft International Standard 24353 and Nordtest Moisture Buffer Value protocol (Rode et al., 2007) propose cyclic (de)sorption measurements. In these, a sample of the finish is conditioned to a specific RH and sealed at all but its normally exposed sides. It is then alternatingly exposed to a high and low ambient humidity, over predefined intervals of time. The sample moisture mass evolution is recorded, and the MBP is obtained from the normalised amplitude: NT defines the Moisture Buffer Value (MBV) by normalisation per m² and % RH change:

$$MBV_{8h} = \frac{m_{8h} - m_{0h}}{A \cdot (\phi_{high} - \phi_{low})} \quad (kg/m^2/\%RH) \qquad (1)$$

in which $m_{8h/0h}$ (kg/m²) is the sample's moisture mass at the end and the start of the high RH interval (see below), A (m²) is the sample's exposed surface, and $\varphi_{high/low}$ (-) is the high/low RH level used in the measurement.

Table 1: limits for MBV classes and exemplary finishes

Class definition	MBV_{8h}-range (g/m²/%RH)	Exemplary finish
negligible	< 0.2	1 cm perlite insulation
limited	0.2 – 0.5	1 cm gypsum plaster
moderate	0.5 – 1.0	1 cm plywood
good	1.0 – 2.0	10 cm flax insulation
excellent	> 2.0	10 cm cellulose insulation

Based on this MBV definition, NT introduces 5 classes of moisture buffering materials. In Table 1, their limits are given (Rode et al., 2007). After a sensitivity study, Roels and Janssen (2006) suggest that the combination of NT's 8/16 h time intervals and 75%/ 33% RH levels with JIS'/ DIS' real thickness and surface transfer coefficient gives the most dependable MBP characterisation. The MBV_{8h} for the exemplary finishes given in Table 1 are determined using this protocol.

Single-object MBP characterization

The MBP of an object can be measured and defined similarly, now without the surface area normalisation:

$$MBV'_{8h} = (m_{8h} - m_{0h}) \,/\, (\phi_{high} - \phi_{low}) \quad (kg/\%RH) \qquad (2)$$

Production-adaptive MBP characterisation

Moisture buffer simulations performed by Janssen and Roels (2009) reveal a crucial shortcoming of NT/JIS/DIS based MBP characterisations. In moisture buffer simulations, the interior humidity response of a room with a hygroscopic finish is calculated. It is shown that MBV_{8h} only yields a dependable MBP of the finish for a moisture production similar to NT's 8/16 h time interval. Shorter productions result in a less unique relation between MBV_{8h} and interior RH amplitude. For that reason, Janssen and Roels (2009) suggest determining the MBP as a weighted average of a long- and short-term value:

$$MBV^{(')}* = \alpha\, MBV^{(')}_{8h} + (1-\alpha)\, MBV^{(')}_{1h} \qquad (3)$$

in which $MBV^{(')}_{8h/1h}$ are the long- and short-term $MBV^{(')}$, α is a weighting factor between 0 and 1 (1 for long production, 0 for short production regime), and $MBV^{(')}*$ is the production-adaptive MBP. $MBV^{(')}_{1h}$ is attained from the original MBV measurement: m_{1h} is used in Eq. 1, instead of m_{8h},. Janssen and Roels (2009) show that such $MBV^{(')}*$ yields a dependable MBP characterisation independent of the moisture production scheme and applicable for both interior finishes and objects.

Room enclosure MBP characterisation

The MBP of a full room enclosure is characterised by superposing the MBP's of the interior finishes and objects:

$$\begin{aligned} HIR^* &= \left(\sum A_k \cdot MBV_k^* + \sum MBV_l^{'*}\right) / V \qquad (4) \\ &= \alpha \cdot HIR_{8h} + (1-\alpha) \cdot HIR_{1h} \quad (kg/m^3/\%RH) \end{aligned}$$

in which HIR (kg/m³/%RH) is the hygric inertia per m³ of room, MBV_k (kg/m²/%RH) and A_k (m²) are the moisture buffer value and area of finish k, MBV'_l (kg/%RH) is the equivalent moisture buffer value of object l and V (m³) is the volume of the room.

Moisture buffer simulations with different surface areas and material combinations (Janssen and Roels, 2009) demonstrate that the superposition in Eq. 4 results in a dependable characterisation of the MBP of room enclosures, including both interior finishes and interior objects.

Quantitative assessment

Simplified quantification models

The HIR* developed above allows qualitatively assessing the moisture buffer potential of room enclosures, by direct comparison of different designs. To quantify these moisture buffering effects, solution of the moisture balance of the building zone is required, with inclusion of the moisture exchanges with the enclosure. The latter can be calculated numerically, or via the effective capacitance (EC) or the effective moisture penetration depth (EMPD) models. All of these have the disadvantage that they have been primarily developed for flat single-material finishes, and not for multilayered multidimensional elements. They do moreover require knowledge of the full moisture capacity and permeability. The numerical approach finally has the added drawback of being computationally expensive. It is shown below that HIR* can be used as input to EC and EMPD models, thus evading the earlier limitations.

Effective moisture penetration depth model

In the EMPD model, the moisture exchange G_{buf} (kg/s) between zone and enclosure is written as:

$$G_{buf} = A \cdot \frac{p_{vi} - p_{vb}}{\frac{1}{\beta} + \frac{d_b}{2.\delta_p}} = A \cdot \xi \cdot d_b \frac{\partial}{\partial t}\left(\frac{p_{vb}}{p_{v,sat}(\theta_b)}\right) \qquad (5)$$

in which p_{vb} (Pa) and θ_b (°C) are the representative vapour pressure and temperature in the buffer layer with thickness d_b (m), and δ_p (s) and ξ (kg/m³) are the vapour permeability and moisture capacity of the buffer layer. Eq. 5 can be rewritten (Janssen and Roels, 2009), such that the moisture exchange is governed only by the effusivity and thickness of the material. It can be shown on the other hand that HIR* is equally governed by these two values. Based on that, the HIR* for the enclosure can be transformed into a fictive material (with effusivity and thickness), which is used in Eq. 5. This allows simple quantification of the moisture buffering.

Effective capacitance model

In the EC model, the buffer layer vapour pressure is assumed always in equilibrium with the vapour pressure in the room. The moisture exchange G_{buf} can be described as:

$$G_{buf} = \frac{\partial M_{buf}}{\partial t} \qquad (5)$$

in which M_{buf} (kg) is the moisture stored in the buffer layer. It can be shown that this is directly related to HIR*, thus allowing quantification of the moisture buffering.

Application example

To illustrate the capability of the HIR*-approach and to stress the importance of a correct characterisation of a room enclosure's hygric inertia, the interior humidity of a small library is simulated for a rainy day, when visitors enter with wet clothes. The library is 14 by 15 m², with a height of 4 meter, and holds 24 book racks of 5 by 1.8 meter. One wall is fully glazed, the other walls are 1 cm gypsum plaster, and a 3 cm wood fibre board acoustical ceiling is applied. Two cases are considered: in the first, only walls and ceiling are considered as buffer, while the second adds the book racks. The HIR_{8h} are 0.55 and 2.65 g/m^3/%RH, demonstrating the weight of the book racks. Nonetheless, many simulation models do not (easily) allow the integration of such interior objects. Figure 1 depicts the predicted interior humidity variations for both cases with both models. It is evident that moisture buffering in interior objects is very important. The HIR* approach presented here has made qualitative and quantitative assessment of these possible.

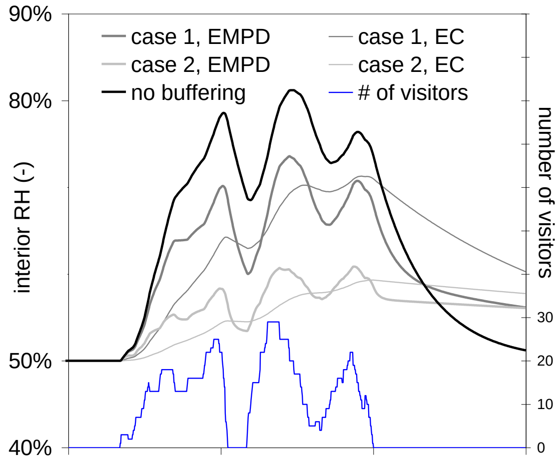

Figure 1: resulting interior humidity variation in library, when considering different buffering elements.

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Dynamic Effects in Porous Media Flow in the Built Environment

Postdoc research project: Gregor A. Scheffler in cooperation with Hans Janssen

Introduction

Porous media flow is omnipresent: it takes place at the microscales of cell biology as well as at the macroscales of oil extraction. Similarly in the built environment, porous media flow plays an essential role, as it governs the transfers of moisture and air, and any chemicals dissolved therein, in built structures. As such, porous media flow determines the durability and sustainability of built structures. It furthermore influences the health and comfort of building occupants: excessive interior humidity levels lead to mould formation and depreciate interior air quality. In most cases moisture is the key determinant for such issues. Thus, to correctly design novel structures or to reliably remedy defective existing ones, dependable estimations of moisture transport in porous media are crucial.

A central concept herein is the moisture retention curve: the relation between the capillary pressure and the moisture content in the porous medium. It is generally presumed that data determined under static conditions remain applicable for transient flow, and vice versa. Recent evidence however indicates that this is not always valid: the capillary pressure – moisture content relation is shown to be affected by the (de)-saturation rates of the moisture transport process involved, the so-called 'dynamic effects', see Fig. 1.

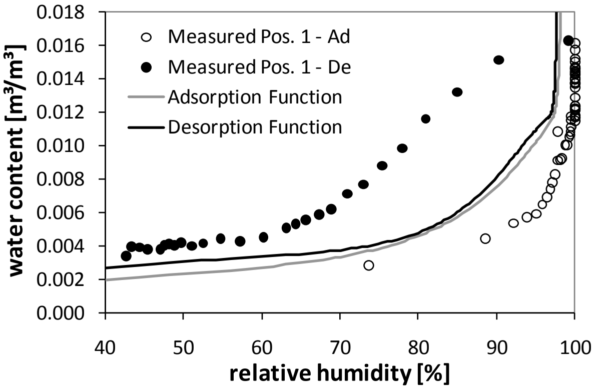

Fig. 1: Comparison of static and dynamic data. Mesured evidence on dynamic effects in the hygroscopic moisture range (Scheffler & Plagge, 2009).

The project aims on further investigation and modelling of these effects. The improved dependability of hygric material properties, and of moisture transport models, will yield more reliability during design and execution of moisture-safe constructions. Such will allow achieving more durable solutions, lower energy consumption and improved sustainable design. The project's impact will however not remain limited to the building physical domain only but will also reverberate in other porous media flow domains.

Objectives and Methodology

This research project aims at evaluating the potential significance of dynamic effects for the assessment of moisture transfer in built structures. The literature provides ample experimental data for soils. Building materials do though generally exhibit a far wider pore size range within one material, and soil results may thus not necessarily apply to building materials. While a substantial experimental investigation was performed for several building materials, more complete measurements in the high moisture content range are still required. The literature similarly shows that a suitable approach for integration of dynamic effects in moisture transport simulations exists. This approach calls for further development and validation. To develop the dependability of moisture transfer assessment, the influence of dynamic effects thus warrants further research with respect to both measurement and modelling.

Measurement

Based on existing dynamic data for building materials in the hygroscopic moisture content range, futher investigations are made with focus on the overhygroscopic range. Instantaneous profile measurements during water absorption and drying are made for different building materials. Two different methods are applied: X-ray attenuation for moisture content measurement and thermocouple psychrometry for moisture potential determination.

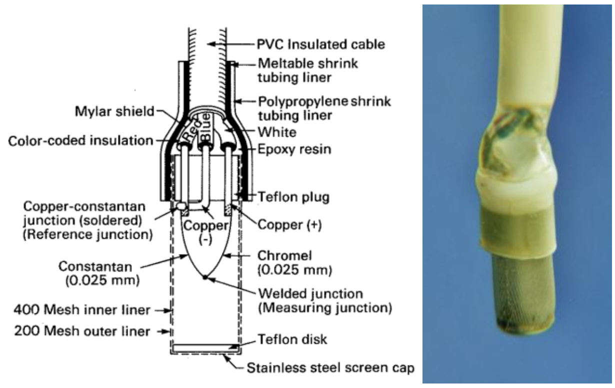

Fig. 2: Design of a thermocouple psychrometer.

Thermocouple psychrometers, see Fig. 2, allow water potential measurement close to saturation, i.e. relative humidities in the range of 95% … 99.98% in a fine resolution. The measurement principle makes use of two thermo-electric effects in a thermocouple junction: the Seebeck-effect and the Peltier-effect. The Peltier-effect causes a cooling while an electric current is applied. Due to this cooling, moisture from the adjacent air condenses on the junction. When the cooling stops, two opposing processes get in equilibrium. One is the heating of the junction from the warmer environment. The other is the cooling due to the evaporation of the condensed water. As long as there is liquid water on the junction which evaporates, the junction temperature will be lower than the ambient air and hence lower than the reference junction. This causes a current flowing through the junction (Seebeck-effect). The corresponding microvolt output is measured and can be related to the moisture potential.

X-ray radiography can be used to determine the moisture content distribution in building materials in a non-destructive way. The incident X-rays become attenuated by the material through which they pass in dependence on the material itself and its thickness. Relating this attenuation of X-rays to the one of the dry material, the moisture content distribution and its spatial and temporal development can be determined.

Fig. 3: X-ray measurement chamber at DTU – Byg.

Modelling

There exist first approaches for modelling of dynamic effects in the literature. These are verified based on the available experimental data. In a second step, this model for 'dynamic effects' description is implemented in a simulation model for moisture transport in built structures. First results of this are already available, as becomes visible in Fig. 4.

The model is improved stepwise and a profound validation is performed, by comparison of simulated results with existing and new experimental data.

Finally, a sensitivity analysis is conducted to investigate the impact of dynamic effects on the overall simulation results. Two levels are distinguished here: material modelling and fundamental investigations under very well defined boundary conditions at the one hand, and general, long-term application studies under real climatic conditions on the other.

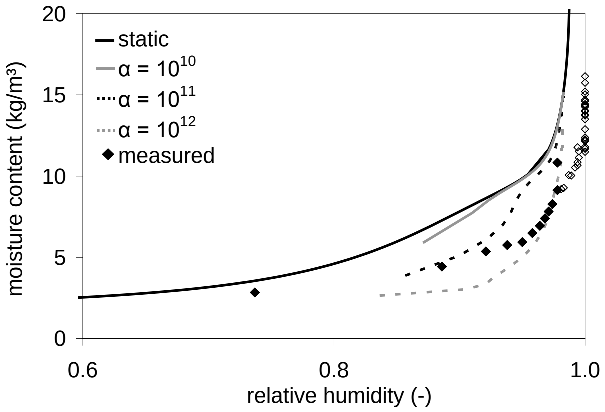

Fig. 4: Comparison of measured and calculated dynamic sorption isotherms (Janssen & Scheffler, 2009).

Anticipated results

This project will first and foremost create a far better understanding of dynamic effects and their impact on moisture transport in built structures particularly, and on porous media flow generally. For moisture transport in built structures the project will affect the methodology for material property determination and the general hygrothermal modelling for performance assessment. These may be considerably improved as transient experiments and simulations are generally used. By integrating dynamic effects in a general numerical model for moisture transport in built structures, both issues can be addressed, as both inverse and standard modelling can be resolved.

As second important benefit from these results, the modelling and implementation of further processes (e.g. salt and VOC transport, two-phase flow) will be based on a more reliable description of moisture transport. This opens other fields of research on a new and high-quality basis. Finally, it has to be stated that while the specific emphasis of this project is put on moisture transport in built structures, the developed modelling is assumed to be similarly applicable to porous media flow in general.

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Modelling Local Hygrothermal Interaction: Local surface transfer coefficients

Research project: Paul Steskens, Hans Janssen, Carsten Rode

Introduction

Within building physics, it is generally accepted that moisture and temperature levels – and their variations in time and space – play a crucial role in both the degradation processes of building components and in the (perceived) quality of the interior environment in a building zone. Previous research has shown that the surface moisture and temperature levels are critical factors in the development of microbiological growth on building surfaces . Similarly, it has been shown that the interior moisture and temperature levels are essential factors in the occupants' comfort and perception of interior air quality.

During the past few decades, there has been quite some development and increased professional use of tools to simulate the processes that are involved in analysis of whole building heat, air, and moisture (HAM) conditions in buildings. Currently, researchers are striving to advance the possibilities to calculate the integrated phenomena of heat, air and moisture flows in the buildings while including the interactions that take place in buildings between the various building materials, components, and room air by coupling a numerical model that describes the airflow in the room with a HAM building component model. Either a computational fluid dynamics (CFD) model or a (sub)zonal airflow model is used to model the local indoor environmental conditions and convective surface transfer coefficients.

Problem statement and objectives

While a CFD model is able to predict local convective surface heat and moisture surface transfer coefficients, the main disadvantage of CFD is that the computational effort is relatively large and that transient, coupled HAM-CFD simulations are not practically feasible. An alternative may be the (sub)zonal airflow model. Regarding the (sub)zonal airflow model, the computational effort of a transient and coupled simulation is relatively small. However, the (sub)zonal models that are currently available are not able to predict local convective surface heat and moisture transfer coefficients. This paper presents the modelling of the local indoor environmental conditions, using a (sub)zonal airflow model, focussing on the prediction of the local interior surface heat and moisture transfer coefficients.

Airflow modelling

A natural convection test case has been selected for analysis. The test case has been described in (Inard, 1996). The test cell consists of a 24 m^3 (3.1 x 3.1 x 2.5m) single volume of which the temperature is kept constant on the faces. Figure 1 presents the setup and the boundary conditions that have been used for the investigations.

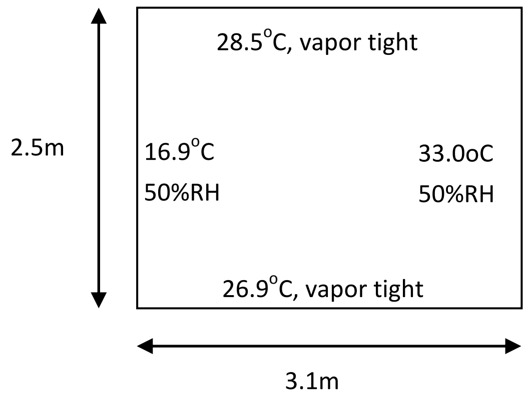

Figure 1: Geometry of the test case

A (sub)zonal airflow model has been used to describe the airflow in the room. First of all, the air in the room has been discretized using 8x10 control volumes. Standard sub-zones are applied in the centre part of the room, while a thermal boundary layer model (Stewart, 2006) describing the flow in the thermal boundary layer near the wall has been applied in these cells.

Surface transfer coefficients

With respect to the walls, local convective surface heat and moisture transfer coefficients have been modelled, based on the experimental work that is reported in (Turner and Flake, 1980), represented by Equation 1.

$$Nu_x = 0.524(Gr_x)^{0.26} \tag{1}$$

$$h = \frac{Nu_x k}{x} \tag{2}$$

where Nu_x is the local Nusselt number, Gr_x is the local Grasshof number, *k* is the thermal conductivity [W m^{-1} K^{-1}], and *x* is the perpendicular coordinate along the wall [m].

The local convective surface heat transfer coefficients of the walls (h) (Eq. 2) have been determined based on the local Grasshof and Nusselt numbers**Error! Reference source not found.**. Regarding the floor and ceiling, average surface transfer coefficients have been applied based on the correlations reported in (Beausoleil-

Morrison, 2000). With respect to the convective surface moisture coefficients (h_M), the Chilton-Colburn analogy has been applied.

Results

A comparison of the predicted temperature and velocity distribution with experimental results (Inard et al., 1996) showed that the numerical results obtained from both the (sub)zonal and the CFD model are comparable. Figure 2 and Figure 3 present a comparison of the local convective surface heat and moisture transfer coefficients resulting from the (sub)zonal airflow model with the average values for the convective surface transfer coefficients obtained by the relationships presented in (Beausoleil-Morrison, 2000), and with the values obtained from the CFD simulation.

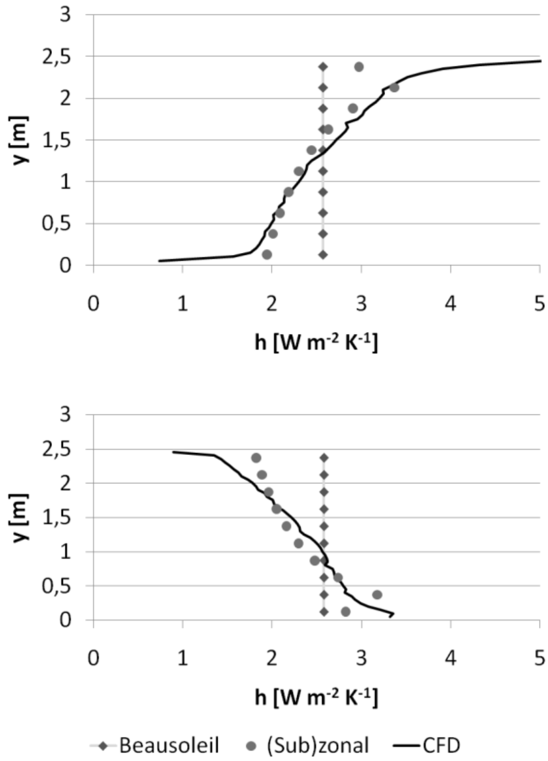

Figure 2: Convective surface heat transfer coefficients for the Western wall (top) and the Eastern wall (bottom) obtained from the relationships presented in (Beausoleil-Morrison 2000), the (sub)zonal models and from CFD.

With respect to the (sub)zonal model, the resulting local surface transfer coefficients are comparable with the coefficients predicted by CFD. In the centre part of the room, the profiles agree well with each other and the error is relatively small, while the deviation between the results increases slightly towards the corners. Moreover, the figures show a large difference between the average surface transfer coefficients and the local surface transfer coefficients predicted by CFD.

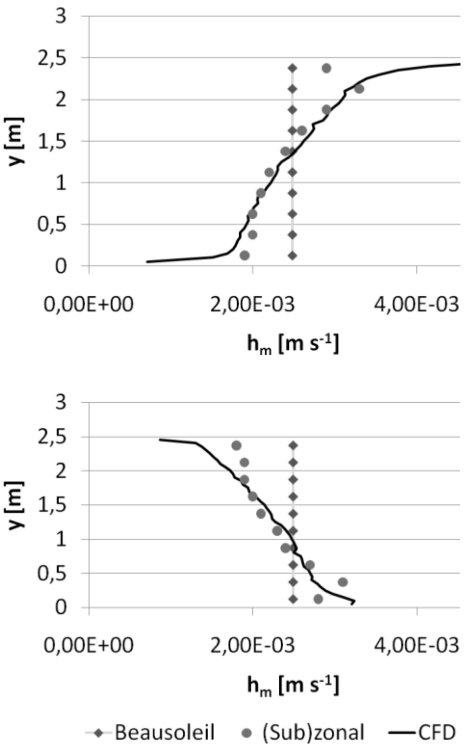

Figure 3: Convective surface moisture transfer coefficients for the Western wall (top) and the Eastern wall (bottom) obtained from the relationships presented in (Beausoleil-Morrison 2000), the (sub)zonal models and from CFD.

Conclusion and Discussion

The research showed that the (sub)zonal model based on the experimental results for natural convection in a rectangular enclosure (Turner and Flake 1980) gives good agreement with the local convective surface transfer coefficients predicted from CFD. The main advantage of the presented (sub)zonal airflow model is that the computational effort is relatively small, while the predictions of the local surface transfer coefficients are relatively accurate. This increases the perspectives with respect to the transient and coupled simulation of indoor environment and HAM transport in the building component.

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Passive houses for the Arctic climate

Ph.D. project: Petra Vladykova with supervisors: Carsten Rode, Toke Rammer Nielsen, Søren Pedersen

Introduction

A Passive House is an ultra-low energy building that requires very little energy for space heating and it can only be realized through an integrated design process leading to a design that uses techniques such as thermal mass, passive solar gain combined with advanced heating, and ventilation systems together with renewable energy sources. Passive Houses are normally built according to a German definition which is suitable for buildings in Central European climates.

The definition of a Passive House needs to be re-evaluated for use in an Arctic climate, where the energy sources are scarce, and the outdoor climate is very severe. In a cold climate region, there will be a further need to increase the amount of thermal insulation, use better windows and having a very air-tight building envelope, and also to use a ventilation system with a highly efficient heat recovery unit. The definition of an Arctic Passive House needs to also recognize the different usage patterns and building traditions in countries in the far north.

The most essential techniques used in Passive houses in Europe are: super-insulation (U-value for walls < 0.15 W/(m^2·K)), triple pane windows (U-value < 0.85 W/(m^2·K)), thermal bridge free construction, fresh air ventilation system with heat recovery (η > 75 %) , solar and internal gains (2.1 W/m^2), see Fig. 1.

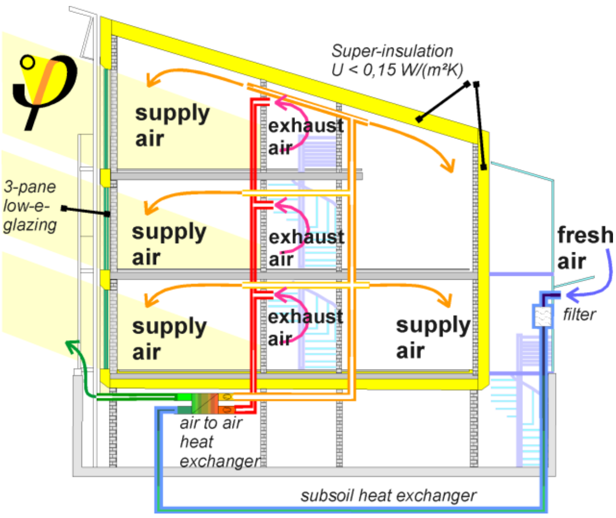

Fig. 1: Section through the Darmstadt Passive house showing the most important low energy techniques (www.passivhaustatung.de , 2009)

Requirements to fulfill: annual heat demand < 15 kWh/m^2, total primary energy demand < 120 kWh/(m^2·a), and the air change by 50 Pa pressurization < 0.6 air changes per hour.

The task is to bring the existing technologies used in European Passive houses to the edge in the challenging climate of the Arctic. The further investigation of Passive house and its use for people includes an optimization of a number of energy factors, transport problems, etc. The project will define a balance between the basic passive house definition and the extreme climatic challenge of the Arctic, but still making it possible to build a Passive house with all its quality in the Arctic using an adapted approach.

Objectives and Methodology

Research questions

Can the German/European definition of a Passive House make use in the Arctic countries, and is it even possible to build it?

How will a European Passive House perform in Greenland?

Could an Arctic Passive House stimulate development of low-energy/passive buildings technology in other climates?

Fig. 2: Sisimiut, Greenland, December 2008

Framework

The Arctic is defined either according to a geographical or a climatological definition (Wikipedia 2009):

The geographical definition is by *Polar Circles* (Arctic and Antarctic), which are at 66°33´38" Northern respectively Southern latitude.

In climatology is used a more "functional" definition, Arctic is defined in terms of the *treeless zone of tundra* and the regions of *permafrost* in the Northern Hemisphere. These are the locations where the average daily summer temperature is below 10 °C, and a condition of permafrost exists in the soil.

The following countries have Arctic conditions: Greenland, Svalbard, Norway, Sweden, Finland, Russia, Alaska, Canada, and Antarctica.

The analytical procedure is to look at the fundamental German definition of a Passive house without active heating and its use for Arctic locations. In theory it is possible to build a Passive house in such a challenging climate, but only at large a investment cost due to a required very high insulation level, and with a need to overcome significant transportation obstacles.

The analysis and breaking up of the fundamental definition into parts will involve more detailed investigation of solar and internal gains, transmission and ventilation heat losses, and indoor climate and heating energy systems. The optimization includes improving of essential things such the building envelope, windows, ventilation systems will lead to improve the overall efficiency of houses.

The results of optimizing the definition will give a new conceptual definition with room of parameters for Arctic Passive house. The input is on finding a balanced optimum between initial investments & energy consumed (including grey energy) & improving efficiency & heat losses.

The modeling and calculations include the analysis of technical components and performances such as thermal insulation, windows, air tightness, and thermal bridges. The modeling of ventilation systems and their provision of warm air to buildings in an extreme climate is to be investigated. The further calculations include energy consumption (primary energy consumption, heating consumption and heating load), distribution of heat losses and sensitivity analysis of essential parts of building (e.g. thickness of insulation, window efficiency, and efficiency of ventilation and heat recovery systems). Thermal comfort criteria for indoor climate are investigated as use of "adaptive thermal comfort" may be applicable for different climate and society.

Fig. 3: New dormitory in Sisimiut, Greenland

Task

Computer models will be used to simulate buildings such as the Low-energy house in Sisimiut, the new dormitory and the "Harresø Passive house" in order to help investigate the possible options: what it will take to make a real Passive house in the Arctic according to the German definition? Will it still be possible to heat the house using only 10 W/m^2? Or will the answer be not to build Passive houses but optimal houses with extreme low consumption, where the temperature will be kept at a reasonable level even after the heating is switched off?

The task is to analyze and find a pragmatic solution with reasonable levels of insulation and best available Passive house technologies and materials, and with clever and compact structures with minimum ventilation loss and still maximum facade exposure to solar radiation. The good and most practical solution depends also on the political climate, societal economy, investments (payback time) in a location where a house is extremely influenced by the outdoor climate.

Fig. 4: Low-energy house in Sisimiut, Greenland

Anticipated results

The project should contribute to answering the question how the goal of a good and well working Passive House can be achieved in Arctic climates. Results of the project are expected to stimulate the development of extreme low energy houses also in more moderate climates.

A Passive house is in principle possible to make everywhere, but the climate in e.g. Greenland is so different that it is not given that the Passive house concept is the most optimal concept, regarding insulation level and payback time for saved energy considering local prices for energy and materials. Therefore a more pragmatic solution would be reasonable where the focus will be put on how the communities and the housing work as whole systems.

References

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6 Activities to develop sustainable buildings

6.1 Introduction

The energy use in buildings for heating, cooling, lighting and equipment is, in Denmark, EU and globally, about 40% of the total energy use. Therefore sustainable buildings without use of energy from fossil fuels are a key element in a general sustainable development with respect to climate and energy. In order to reach the climate goals, the future energy supply for buildings shall be carbon neutral. This can only be achieved when renewable energy is applied in combination with massive energy savings in the existing building stock and only if all new buildings are energy efficient.

6.2 Challenges and solutions

Research at the Section for Building Physics and Services has show that up to 80% reduction in energy use in buildings is possible before 2050 and that this is to a large extent economically acceptable, especially when combined with general maintenance. Thus the challenge is to combine the technical innovation with an economic optimization and make sure the solutions are implemented in general and before 2050. Governments must install incentives and regulations that ensure that the savings potential is exploited. New incentive schemes must be developed and the overall balance between investments in energy savings in the building sector needs to be balanced towards investments in energy supply from non-fossil fuels in other sectors.

6.2.1 The basic technology is here

It is possible today to build houses with 90% less energy demand than existing buildings within marginal extra costs. This can be done without compromising architectural quality, usability or indoor climate. There is a big potential for further technical innovations within the building sector that may be used in combination with an economic optimization. Also here national regulations and incentives are needed to ensure a rapid shift in energy use of the building stock.

6.2.2 But more research and development are needed

The following potential technical innovations to develop cost effective products and processes have been identified:

Products (components and systems):

- Highly insulating building envelopes for new buildings and for retrofitting.
- Dynamic window systems including solar shadings with a positive net energy gain in the heating season, a minimum solar gain in the cooling season and a high transmittance of diffuse daylight.
- Ventilation systems that provide healthy and comfortable indoor environment with heat recovery and such a low pressure drop and energy use of the fan that the ventilation system can also be used for venting and night ventilation to cool the building.
- Lighting systems based on new energy efficient LED light sources that are designed and controlled to be used only when needed due to human activities and insufficient daylight.
- Systems for heating of rooms and domestic hot water that only need a supply temperature of 50ºC and have a low and uniform power consumption during the day.
- Low temperature (50/20ºC) district heating systems that can supply low energy houses with heat from multiple renewable heat sources with a heat loss of less than 15% and at a competitive cost.
- Solar heating system combined with a heat pump system to supply heating to buildings outside areas with district heating.

- Systems for intelligent control and continuous commissioning of the technical building services and heating supply systems based on dynamic calculations of the indoor environment and energy use of the buildings for predicted and measured weather data.
- Systems for integration of intelligent buildings in an intelligent energy system.

Processes (design, construction and operation):

- Integrated design and optimization of new buildings and retrofitting of existing buildings with respect to indoor environment, energy use, service life time and total economy.
- Integrated construction and operation of buildings in order to obtain and maintain the predicted performances by use of continuous commissioning and solutions prepared for repair.

The innovation and implementation of the new technologies also stimulate the transition of the building sector from being tradition based to become knowledge based.

6.3 Implementation issues

Most implementation issues are economical and societal. However, continued research, development and demonstration of energy saving technology are needed in order to speed up implementation and reduce costs of implementation.

6.3.1 Governmental regulation is needed:

The following actions to implement the technical innovations in the building stock have been identified:

- strengthen building regulations with respect to energy use and indoor environment of both new and existing building
- set up local energy plans for cities with respect to heating supply by district heating
- demonstration projects to validate technology and facilitate implementation in the building sector
- enhance education and make the building sector knowledge based

The challenge is to bring the individual technologies into use through an integrated design process that reconciles energy savings, indoor climate, construction requirements, architecture and end user demands with a good total economy based on long service life and low cost.

6.3.2 Buildings are part of an energy system:

Challenges include the interaction between the individual building owner’s perspective and the energy supplier’s perspective. New incentives and regulations are needed to develop overall efficient systems that balance investments between sectors. This is particularly important in the building sector where the renewal time is very large compared to normal economic time scales. Technical research and development challenges include:

- replacement or retrofitting of existing building stock to low energy buildings
- low demand energy supply systems (district heating/cooling)
- intelligently controlled buildings and energy systems that can make use of weather forecasts to find the optimal operation strategy for the whole system.

6.4 Closure

The Section for Building Physics and Services is going to continue the work on the development and implementation of sustainable buildings in research, education and innovation as outlined above.